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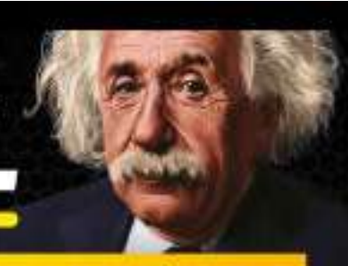

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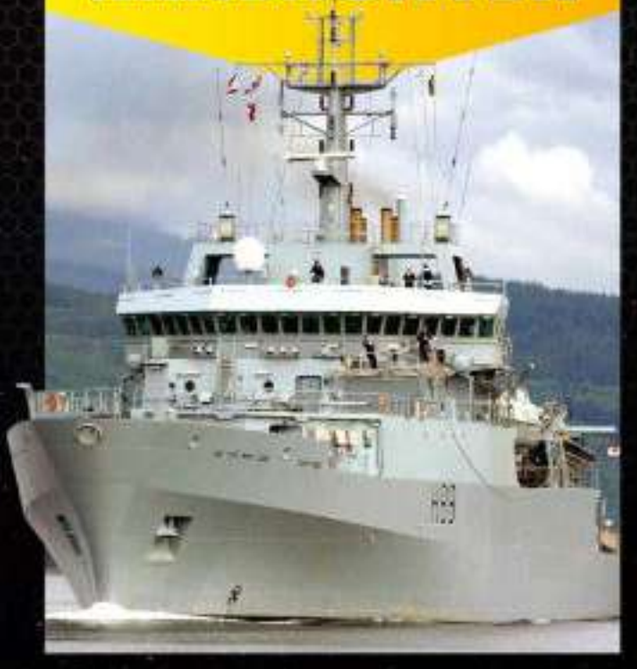

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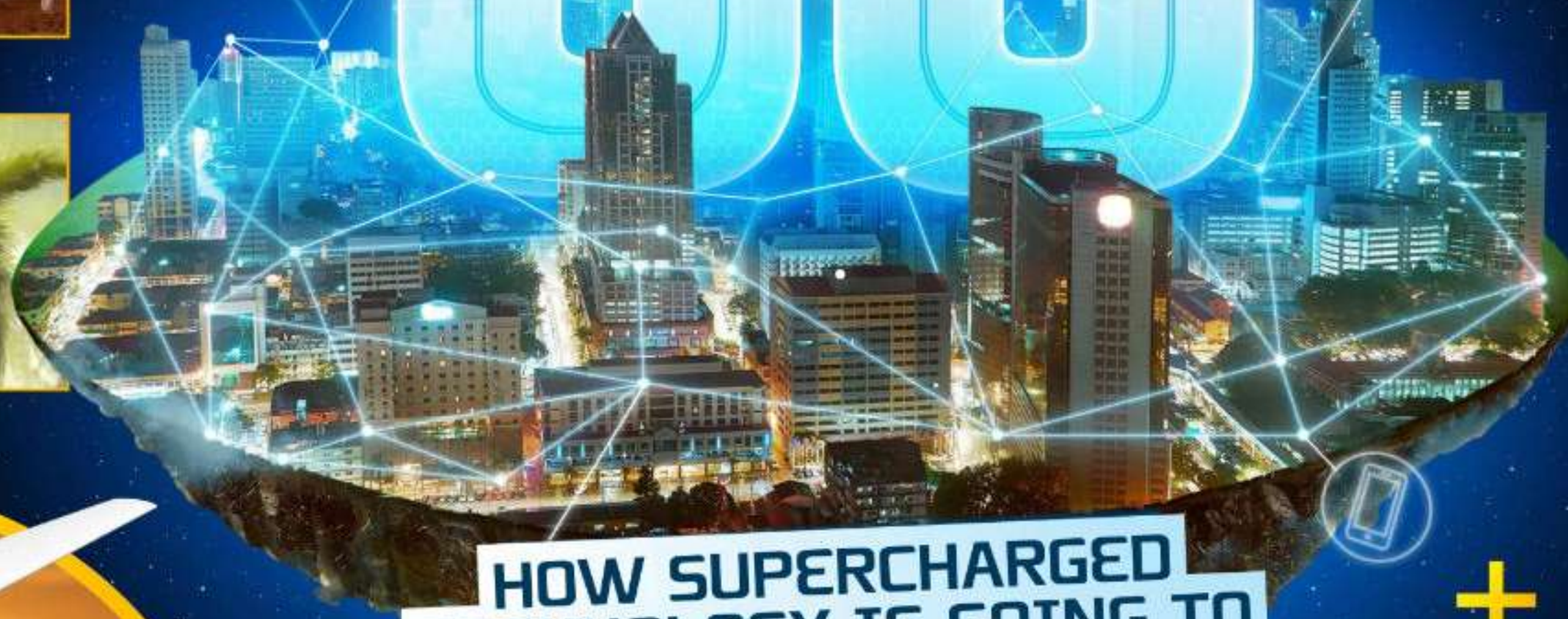

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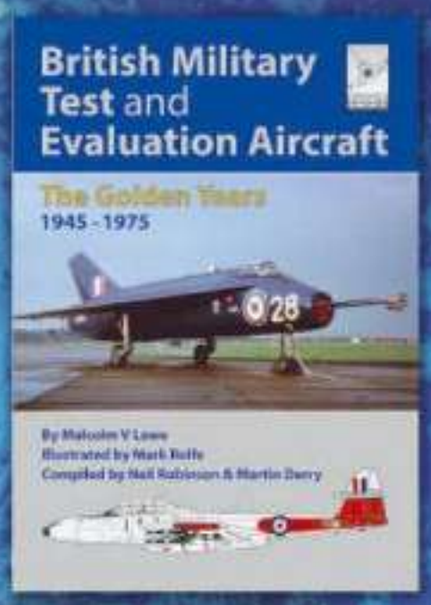

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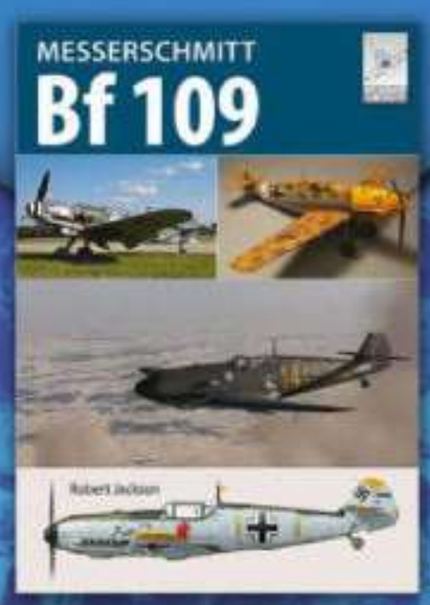

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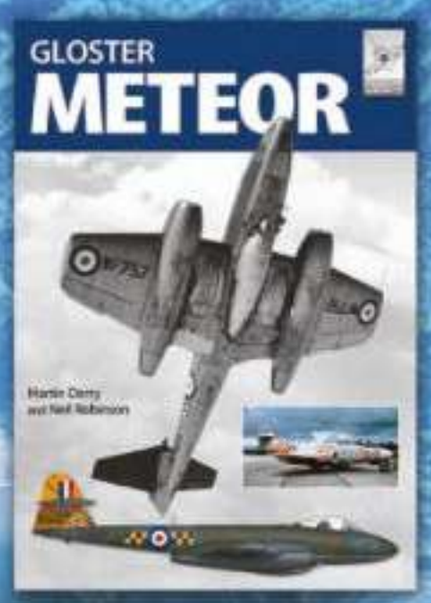

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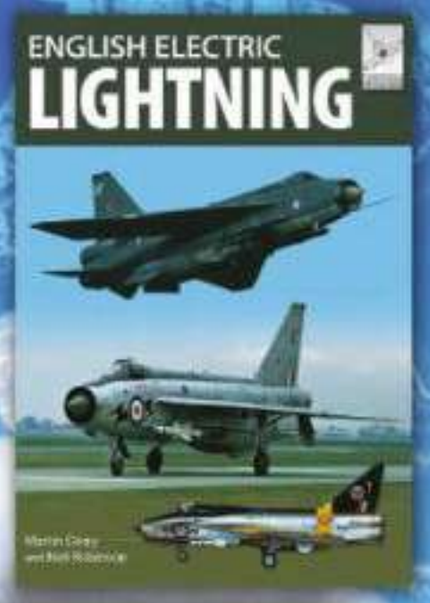

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ISSUE 129

WELCOME

The magazine that feeds minds!

"It will have the same impact as electricity and steam had in the previous industry revolutions"

How 5G will supercharge your life, page 22

The scope of 5G's cellular networks is probably going to blow even the early adopters away. It goes way beyond simply streaming video faster on your mobile phone: this reliable and super-quick technology is itself a technology enabler. When 5G rolls out, driverless cars will become ubiquitous, surgeons will be able to operate without being in the same room as the patient, advertisers will be able to put moving images on any surface. And your local school? 5G is coming to a classroom near you soon! Read more about how 5G works on page 22. Enjoy the issue!

Ben Biggs Editor

For exclusive **HIW** news and offers, sign up to our mailing list **howitworksdaily.com/newsletter**

Meet the team...

James
Production Editor
On page 78 we take a look at some of the colossal creepy-crawlies that once roamed the Earth – including a terrifying giant scorpion.

Scott
Staff Writer
Is a bird brain so different from that of a rabbit? We discover what's between the eyes of the world's animals on page 70.

Baljeet
Research Editor
Will we ever really be able to travel back in time? Find out with our beginner's guide to time travel over on page 36.

Duncan
Senior Art Editor
See what early human habitats on Mars might look like on page 72 (hint – it's a lot nicer than what Mark Whatney has in *The Martian*).

Ailsa Harvey
Staff Writer
Contactless cards are transforming the way we pay, but are they safe? Discover how NFC hands over your money through the air on page 34.

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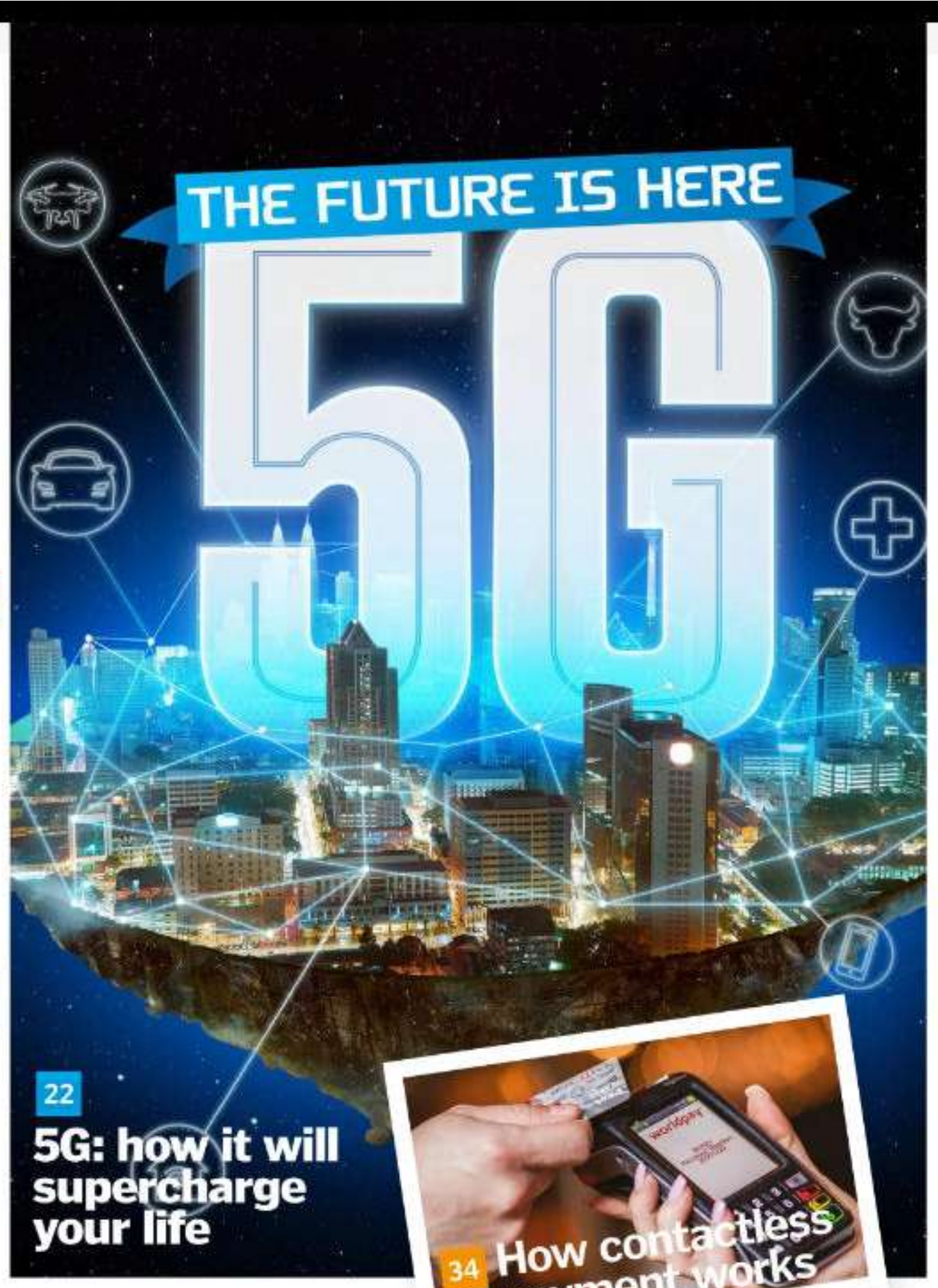

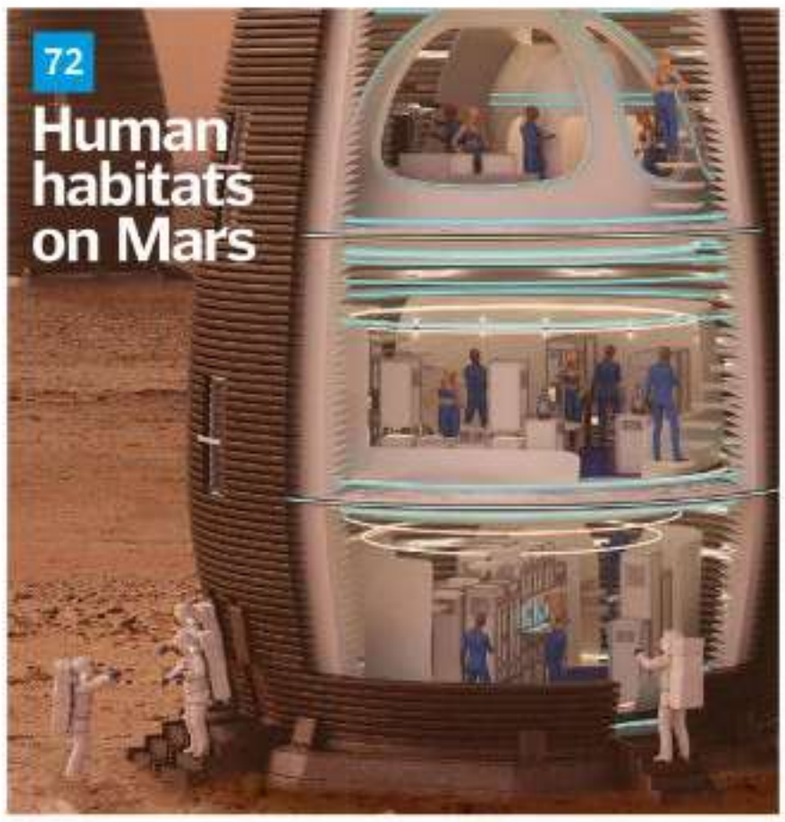

MEET THIS ISSUE'S EXPERTS...

James Horton
Former **HIW** member James is a biochemist and biotechnologist. He is currently doing a PhD in machine learning and evolutionary theory.

Jo Stass
Writer and editor Jo is particularly interested in the natural world and learning about the latest in technological innovations.

Jodie Tyley
The former editor of **HIW** and **All About History** has tackled many topics in her career, from science fiction to science fact, and Henry VIII to honey badgers.

Laura Mears
Biomedical scientist Laura escaped the lab to write about science and is now working towards her PhD in computational evolution.

Stephen Ashby
Stephen is a writer and editor with video games and computer tech expertise. He is endlessly intrigued by Earth science.

Steve Wright
Steve has worked as an editor on many publications. He particularly enjoys history feature writing and regularly writes literature and film reviews.

Amy Grisdale
Volunteer animal worker Amy has an enormous breadth of experience on animal and conservation projects. She specialises in environmental topics.

Tom Lean
Tom is a historian of science at the British Library, working on oral history projects. His first book, *Electronic Dreams*, was published in 2016.

REGULARS

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Page 83

Victoria Williams
Evolutionary biologist and keen writer Vicky is fascinated by the natural world and is happiest when she's outdoors.

Lee Cavendish
Avid stargazer Lee writes for our sister magazine, **All About Space**, has a degree in observational astronomy and loves a bit of technology writing, too.

Dr Andrew May
Andrew has a PhD in astrophysics and 30 years in public and private industry. He enjoys space writing and has written several books.

Jack Parsons
A self-confessed technophile, Jack has a keen interest in gadgets and wearable tech, but also loves to write about projects with much grander ambitions.

Jonny O'Callaghan
With a background in astrophysics, former **HIW** and **All About Space** writer Jonny enjoys delving into the wonders of space and space missions.

Dying alga's green gift

This is an euglenoid alga, a tiny water-dwelling organism with a whip-like appendage that it uses to move through the water. The lake this one was taken from in Vietnam was heavily polluted. In this image, shot using a scanning electron microscope (SEM) and digitally coloured, the alga is dying, releasing the photosynthetic chloroplasts that produce its energy. It was taken by Steve Gschmeissner for The Royal Photographic Society's science photography competition. You can find out about this year's Science Photographer of the Year competition at rps.org/spoty.

Air traffic control drone

Above Reno, Nevada, a drone monitors the airspace as a part of NASA's new unmanned air traffic management system. It's the first of two drone test flights aiming to make the airways safe as a new wave of low-altitude, unmanned operations take off. As well as directing low-altitude urban airspaces and enforcing flight corridors, NASA's system will provide weather warnings. It will manage drones, gliders, helicopters and other aircraft flying below 120 metres.

Big cat of the reptile world

This is a male panther chameleon from Nosy Be island off the coast of Madagascar. Panther chameleons from different parts of Madagascar are distinguished by their colouring – in different areas they tend to be red, green and orange. They can change colour within a certain range, as a social display or to match their environment. They have a transparent outer layer of skin, and beneath is a layer of chromatophore cells filled with coloured pigment. A change in mood or temperature expands some cells and contracts others, releasing certain pigments and displaying distinct colours.

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SCIENCE

New form of gold created

Words by **Yasemin Saplakoglu**

Under extreme conditions gold rearranges its atoms and forms a previously unknown structure. When the pressures are pushed to the equivalent of those at the centre of the Earth, the gold gets even weirder.

This finding comes from a new study in which researchers from the Lawrence Livermore National Laboratory (LLNL) and the Carnegie Institution for Science practised some 21st-century alchemy at the Argonne National Laboratory in Illinois, US. Using a high-energy laser, researchers heated gold to extreme temperatures and compressed it to pressures as high as those found at the Earth's centre.

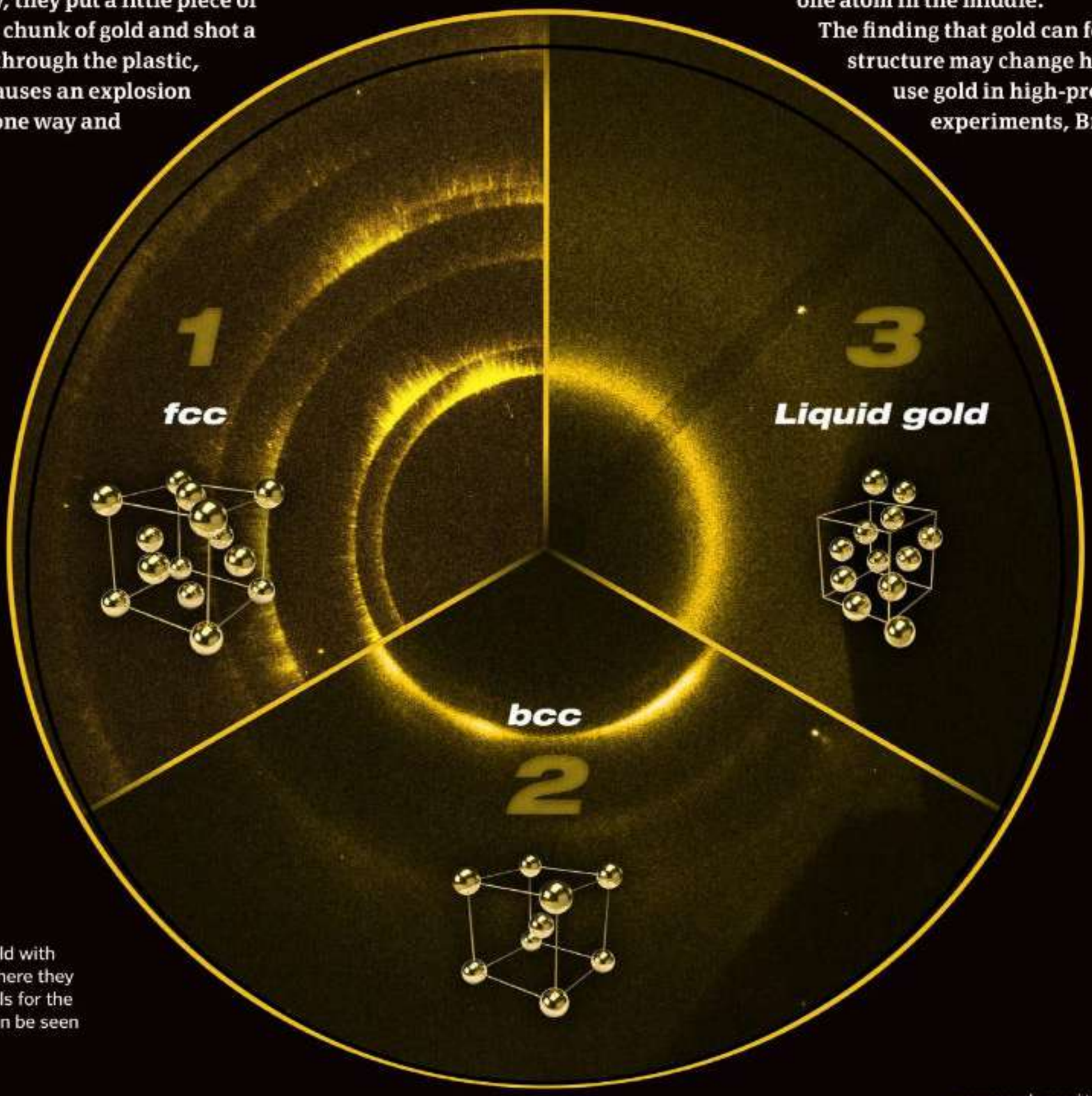
More specifically, they put a little piece of plastic in front of a chunk of gold and shot a high-energy laser through the plastic, which "basically causes an explosion that sends plastic one way and shockwaves in the opposite direction," said lead author Richard Briggs, a postdoctoral scientist at LLNL. Those shockwaves hit the gold and caused it to compress and heat up extremely quickly, within nanoseconds.

They then hit the gold with x-rays and detected where the x-rays bounced off in order to figure out its structure. It's "the first time that we've ever been able to reach such high-pressure and high-temperature conditions and look at them at the same time using x-rays," Briggs told **Live Science**.

What they saw was "certainly a surprise". Gold usually forms a crystalline structure that scientists call face-centred cubic (fcc). Imagine a cube like a die. Atoms would sit on each corner and each face, Briggs said. But most experiments conducted on gold have involved compressing it slowly and at room temperature, he added. Because it so loyally forms this face-centred cubic structure, gold has been used as a kind of 'standard' in high-pressure experiments to calculate pressure, Briggs explained.

When the team rapidly compressed the gold at high temperatures, it formed what's called the body-centred cubic (bcc) structure. This more open structure packs atoms into a space in a less efficient way, so the gold doesn't prefer to be in this form. If you were to imagine the die again, it would be as if atoms sat on each corner, with just one atom in the middle.

The finding that gold can form this structure may change how scientists use gold in high-pressure experiments, Briggs said.



Researchers hit the gold with x-rays and detected where they bounced off (the signals for the different structures can be seen in this image)

IN ASSOCIATION WITH LIVESCIENCE

Made from Chernobyl aquifer water and radioactive rye, Atomik vodka is the first consumer product to come out of the Chernobyl exclusion zone in 33 years

PLANET EARTH

New vodka made from radioactive grain

Words by **Brandon Specktor**

"The rye that the Atomik founders grew in the exclusion zone for their vodka tested positive for radiation"

Thrill seekers visiting the ruins of the Chernobyl nuclear power plant in Ukraine may soon be able to take a piece of the site's radioactive history home with them – in their livers. A team of scientists from the UK and Ukraine have just produced the first bottle of what they're calling Atomik vodka: artisanal spirits made from water and grain harvested in the reactor's once-forbidden exclusion zone.

Though the 2,600-square-kilometre zone surrounding the plant was initially declared uninhabitable by humans for 24,000 years following the 1986 meltdown, the makers of Atomik assured BBC News reporters that their product is no more radioactive than any other liquor on the market.

Part of that is because much of the exclusion zone is not as dangerous as it was feared to be 33 years ago. Some radiation hotspots – such as the Red Forest, where much of the radioactive material from the reactor spilled – remain off-limits. However, for the most part, the risk of radiation contamination in much of the exclusion zone is now considered 'negligible' by the Ukrainian government, which reopened the zone to tourism nearly a decade ago.

According to Anders Moller, a biologist who's spent several weeks a year studying the exclusion zone for the past few decades, local crops are often contaminated with radiation and can cause "serious problems" if ingested.

Sure enough, the rye that the Atomik founders grew in the exclusion zone for their vodka tested positive for radiation. However, according to Atomik co-founder and University of Portsmouth professor Jim Smith, all traces of contamination disappear in the distillation process, during which the fermented liquid gets purified and water and other diluting substances are removed. "Any chemist will tell you, when you distil something, impurities stay in the waste product," Smith told the BBC. Radiation tests conducted by scientists at the University of Southampton confirmed the product to be as safe as any other hard liquor that's on sale.

Just one bottle of Atomik vodka exists at the moment, but the founders hope to cap at least 500 others by year's end and sell them to thirsty Chernobyl tourists.

This piglet squid has a mantle (head) full of ammonia to stay afloat

ANIMALS

'Piglet squid' spotted in deep sea dive

Words by **Rafi Letzter**

Marine scientists have released a stunning video of a strange critter, the piglet squid, floating along with its tentacles waving above its head in the central Pacific Ocean near Palmyra Atoll.

Scientists spotted the squid about 1,385 metres below the ocean surface, while aboard the exploration vehicle (E/V) Nautilus. "What are you?" one of the voices in the video can be heard asking, as the small creature comes into view. "Is that a squid? I think it's a squid. It's like a bloated squid with tiny tentacles and a little hat that's waving around. And it looks like it's got a massive, inflated mantle cavity. I've never seen anything quite like this before."

That's an accurate description of the piglet squid, which is also known for its siphon that looks like the nose of a young pig. Piglet squids, like all cephalopods, have radically different bodies from animals that we're used to seeing on land. The piglet squid's unusual mantle-to-legs ratio is, in part, a consequence of how it moves through the water. According to Nautilus scientists, that mantle is filled with ammonia, which the squid uses to control its buoyancy.

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SPACE

Skywatching spider photobombs a meteor shower

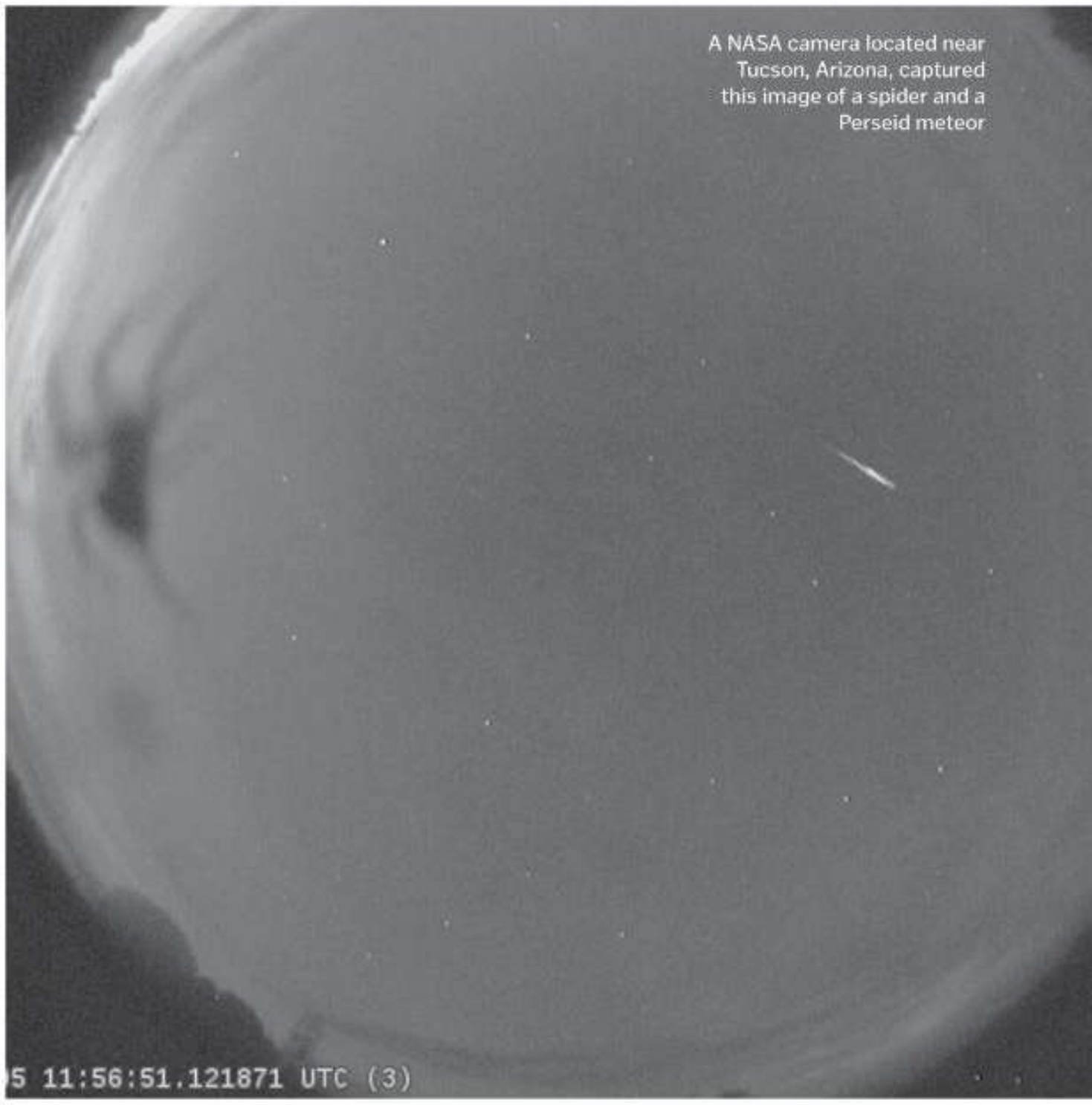
Words by **Meghan Bartels**

How do you spot a shooting star? Well, you don't look for eight legs, that's for sure. But a NASA camera designed to photograph meteors spotted more than it bargained for during the Perseid meteor shower, when a curious spider stopped by.

The photograph was taken at Mt. Lemmon SkyCenter near Tucson, Arizona, on 5 August 2019. NASA maintains a network of 17 all-sky cameras, which capture black-and-white images of the entire sky using a fish-eye lens. The cameras are designed to spot fireballs, which are meteors that enter Earth's atmosphere in a streak brighter in the sky than Venus.

All-sky cameras regularly spot critters that are a little more terrestrial than meteors. NASA has previously published photos of a bug, an owl and a small bird stopping by an all-sky camera. And this recent spider visit isn't the first time NASA has dealt with a photogenic arachnid: in 2007, a plumper spider crawled over a camera that was poised to watch the launch of the space shuttle Atlantis.

The Perseid meteor shower is traditionally the best one of the year, but this year the streakers are difficult to make out against the glow of the waxing moon. The Perseids peaked on 12 August this year, when skywatchers spotted between ten and 15 meteors per hour. The meteor shower continued through to 24 August. The Perseids happen when Earth plows through debris surrounding Comet Swift-Tuttle.



A NASA camera located near Tucson, Arizona, captured this image of a spider and a Perseid meteor

IN ASSOCIATION WITH LIVESCIENCE

ANIMALS

Staring at seagulls stops them stealing

Words by **Mindy Weisberger**

At the beach and on the boardwalk, gulls have a bad reputation for swooping down on unsuspecting people to steal their food. But scientists recently discovered there's a rather simple solution for deterring these avian thieves: just stare at them.

Whereas a gull might be tempted to swipe your snack when you're distracted, they're less likely to come near if you pay attention to them, researchers recently reported. Their experiments demonstrated that gulls were more cautious about approaching a tempting treat if there was a person nearby who was watching them closely. However, the scientists also found that far fewer of the birds than expected showed interest in investigating the food at all when being stared at.

For the study, researchers tested the behaviour of herring gulls (*Larus argentatus*); these large, omnivorous seabirds are found year-round in coastal regions around the UK, according to the Royal Society for the Protection of Birds (RSPB). The scientists approached 74 herring gulls in coastal towns in Cornwall, tempting them with weighted bags of fried potatoes. Most of the birds declined to cooperate and promptly flew away. Only 19 gulls were curious or hungry enough to linger, allowing the scientists to place the bag on the ground and retreat a short distance away, waiting in a crouched position to see if a gull would approach. Whenever a bird showed interest in the food bag, the experimenter would either ignore the gull or stare at it intently. Both trials would continue until the bird either pecked at the food bag or 300 seconds elapsed with no approach.

During the tests in which the researchers looked away, all of the gulls touched the food. Gulls took "significantly longer" – about 21 seconds more, on average – to touch the food if they were being watched, and six of the watched gulls wouldn't tap at the food at all, the researchers reported.

But there was also a lot of variation in the gulls' responses; some approached more slowly than others, while others appeared not to notice the researcher's stare. Overall, the gulls' behaviour suggested that they would be more likely to stay away from food if humans were close to the birds, the authors wrote.

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Staring down a seagull has been shown to slow down their advances towards our lunch

Both children and adults will be enrolled in a new genetic editing trial to treat an inherited eye disorder

HEALTH

Gene editing trial to treat blindness

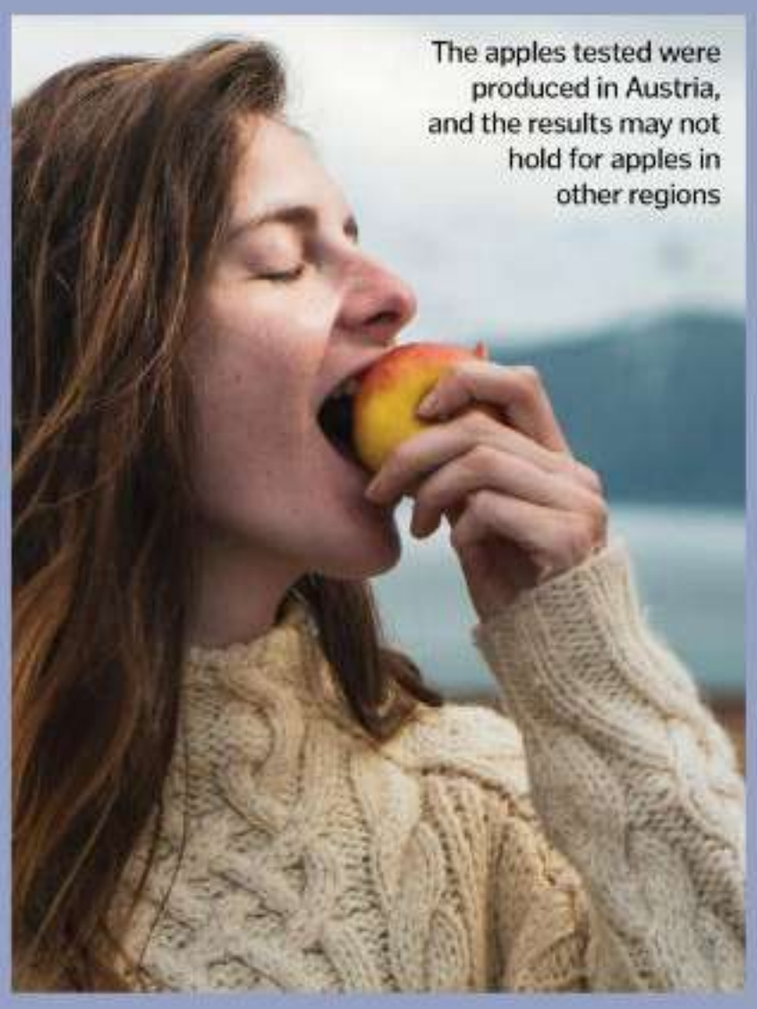
Words by **Rachael Rettner**

The first study to test the gene-editing technology CRISPR inside the human body is about to get underway in the United States, according to news reports. The study plans to use CRISPR to treat an inherited eye disorder that causes blindness, the Associated Press reported.

People with this condition have a mutation in a gene that affects the function of the retina, the light-sensitive cells at the back of the eye that are essential for normal vision. The condition is a form of Leber congenital amaurosis, one of the most common causes of childhood blindness that affects about two to three newborns out of every 100,000, according to the National Institutes of Health.

The treatment will correct the mutation using CRISPR, a tool that enables researchers to precisely edit DNA in a specific spot. Researchers will use an injection to deliver the treatment directly to the light-sensitive cells, according to a statement from Editas Medicine, the company that is conducting the study, along with Allergan. The trial will enrol 18 patients, both children (ages three and up) and adults.

This study is different from the controversial research of a scientist in China who used CRISPR to edit the genomes of twin babies last year. In that case, the DNA of embryos were edited, and the gene alterations could be passed down to the next generation. In the new study, DNA edits made in the patients cannot be passed down to their offspring.



The apples tested were produced in Austria, and the results may not hold for apples in other regions

HEALTH

Organic apples boost bacteria

Words by **Nicoletta Lanese**

Next time you chomp into a crunchy apple, in addition to enjoying the sweet taste you can think about all the possibly beneficial bacteria you are consuming. New research suggests an apple is teeming with about 90 million bacteria. And if you're looking for the best 'bugs' for your gut, you may want to go organic. The researchers found that fresh, organic apples may harbour a more diverse and well-balanced microbiome than conventionally produced apples.

Most of the bacteria, they found, live in the core of the apple, which includes the seeds (about 38 million), the calyx end (22 million) and the stem end (10 million). The fruit pulp holds about 20 million bacterial cells, while the peel is host to just 1.6 million.

Organic apples also bested conventional ones in terms of how diverse their microbiomes were, something that could impact the fruit's taste."Methylobacterium, [a bacterium] known to enhance the biosynthesis of strawberry flavour compounds, was significantly more abundant in organic apples," Gabriele Berg, a biologist and biotechnologist, reported. The tasty compounds accumulate in the peel and pulp. "The highly diverse microbiome of organically managed apples might probably limit or hamper the abundance of human pathogens," researchers wrote in their paper.

IN ASSOCIATION WITH
LIVESCIENCE

If any creature could survive a crash-landing on the Moon, it would probably be a tardigrade

SPACE

Lunar crash strands thousands of tiny bears on the Moon

Words by **Mindy Weisberger**

When you look up at the Moon, there may now be a few thousand water bears looking back at you. The Israeli spacecraft Beresheet crashed into the Moon during a failed landing attempt on 11 April. In doing so, it may have strewn the lunar surface with thousands of dehydrated tardigrades, also known as water bears.

Beresheet was a robotic lander. Although it didn't transport astronauts, it carried human DNA samples, along with the tardigrades and 30 million very small digitised pages of information about human society and culture. However, it's unknown if the archive – and the water bears – survived the impact when Beresheet crashed.

The tardigrades and the human DNA were late additions to the mission, added just a few weeks before Beresheet launched on 22 February. Much like Cretaceous fossils locked in amber, the DNA samples and tardigrades were sealed in a resin layer protecting the DVD-sized lunar library, while thousands more tardigrades were poured onto the sticky tape that held the archive in place on the spacecraft.

But why send tardigrades to the Moon? Tardigrades are microscopic creatures that measure between 0.05 and 1.2 millimetres long. They have endearingly tubby bodies and eight legs tipped with tiny 'hands'. But tardigrades are as well known for their near-indestructibility as they are for their cuteness. Tardigrades can survive conditions that would be deadly to any other form of life, weathering temperature extremes of -200 degrees Celsius to more than 149 degrees Celsius. They can also survive exposure to the radiation and vacuum of space.

"Tardigrades are as well known for their near-indestructibility as they are for their cuteness"

Another tardigrade superpower is their ability to dehydrate their bodies into a state known as a 'tun'. They retract their heads and legs, expel the water from their bodies and shrivel up into a tiny ball – and scientists have found that tardigrades can revive from this dehydrated state after ten years or more.

So whether any of these Beresheet tardigrades are biding their time in this state in a lunar impact crater, waiting until they can be resuscitated, only time will tell.

© Getty

The Amazon is the largest rainforest on Earth, absorbing 2 billion tons of carbon dioxide every year and releasing 20 per cent of the Earth's oxygen

PLANET EARTH

Satellite snaps devastating Amazon deforestation

Words by **Brandon Specktor**

Deforestation in the Amazon rainforest increased by 278 per cent in July 2019 compared with July 2018, resulting in the destruction of 2,253 square kilometres of vegetation, new satellite data from the Brazilian National Institute for Space Research (INPE) shows. That's an area about twice the size of the city of Los Angeles. And, while the forest still spans some 5.5 million square kilometres, the spike in tree loss is part of a dangerous trend.

According to the Associated Press, this is the single biggest surge in rainforest destruction since INPE began monitoring deforestation with its current methodology in 2014. The data comes courtesy of INPE's satellite monitoring program, DETER (Detection of Deforestation in Real Time), which launched in 2004 to help INPE scientists detect and prevent illegal deforestation in the Amazon.

The release falls in the midst of an ongoing feud between INPE scientists and Brazilian President Jair Bolsonaro, a climate change sceptic who vowed on the campaign trail to open more of the Amazon to various mining, logging and agricultural interests, despite environmental protections on the land.

On 2 August Bolsonaro fired then-head of INPE Ricardo Galvão after the agency posted satellite data showing an 88 per cent deforestation increase in June 2019 compared with June 2018.

In a statement announcing his termination, Galvão defended INPE's work and called the president's decision "an embarrassment". It is not, however, much of a surprise. Bolsonaro's attack on INPE follows seven months of policy decisions that weaken environmental legislation and science agencies while empowering business interests, the AP reported.

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WISH LIST

The latest **SPORT** tech

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Like the whack-a-mole of workout gadgets, BlazePods are touch-sensitive light-up pods that act as a visual cue in a training session. Using either predetermined training programs or a self-designed session, these compact workout accessories are personalisable to your training needs. Intended to improve your speed, agility and reaction time, the BlazePods record the time each pod in a kit is touched, enabling you to monitor your training progress.

Smart Rope

■ Price: **£79.95 / $79.95**
tangramfactory.com

It's difficult to imagine how a skipping rope can become hi-tech. However, the Smart Rope appears on the digital scene by recording each skip and displaying a real-time counter through LED lights. It utilises a phenomena known as the persistence of vision: 23 LED lights positioned along the rope light up at different points while skipping, which creates a glowing image of your skip number, apparently floating in mid-air. Using the accompanying Smart Gym app, the user can keep track of their skips, calories burnt and any preprogrammed training sessions.

© Tangram

Swim Coach Communicator

■ Price: **£199 / $149.99**
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When your ears are filled with water, it's hard to hear the calls of a swimming coach while swimming. With the Swim Coach Communicator, coach and athletes can stay in contact during a swim to offer real-time instruction to improve stroke, pace and form. These simple Bluetooth-connected headphones are waterproof up to three metres, and using the FINIS live app, coaches can talk with swimmers in the pool at the touch of a button.

© Finis

Hedkayse ONE

■ Price: **£150 (approx $180)**
hedkayse.com

Ditching traditional hard polystyrene for their own unique 'Enkayse' material, Hedkayse is a first in foldable helmet design for cyclists. As a multi-impact helmet, the Hedkayse ONE can handle the bumps and scrapes of everyday life, while neatly folding into a backpack. Certified to EU safety standards, this versatile helmet is a great way to stay safe on the streets.

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■ Price: **£171 / $229.99**
sportsperformancetracking.com

Understanding how a team is performing on the field is key to achieving future success in any sports team. The SPT 2 can provide in-depth statistics of each player wearing the compact tracking device, as well as the entire team's performance. From players' highest speeds to a heat map of player positions during a game, the accompanying analytic software provides a whole host of information for tailored training.

© SPT

Polaroid Pop

■ Price: **£199.99 / $199.99**
polaroid.com

Combining the nostalgia of polaroid print-outs with a modern-day digital camera, the Polaroid Pop is an instant print camera that's great for capturing sporting moments. Equipped with an LCD touchscreen, a 20-megapixel CMOS sensor and HD video, the Pop snaps and prints images in great quality. Bluetooth and wireless connections also enable the Pop to connect with your Smartphone to print out images from your gallery.

© Polaroid

APPS & GAMES

NBA AR Basketball

■ Developer: **NBA Properties, Inc.**
■ Price: **Free / Google Play / App Store**

Bringing augmented reality and professional basketball together, this app enables you to virtually step onto the court to access behind-the-scene videos as well as interactive games.

Nike Training Club

■ Developer: **Nike, Inc.**
■ Price: **Free / Google Play / App Store**

This personal trainer app offers users a whole range of personalised workouts and drills by Nike experts, as well as from elite athletes such as Cristiano Ronaldo.

TacticalPad

■ Developer: **Temma Software - TacticalPad**
■ Price: **Free / Google Play / App Store**

Plan out your team's strategy with this tactical app. Using its 3D modelling and animated features, TacticalPad allows you to create virtual matches – great for coaching and performance analytics.

Sleep Time

■ Developer: **Azumio Inc.**
■ Price: **Free / Google Play / App Store**

By placing your smartphone under your pillow, track your REM and sleep cycle with this app, so you can understand how best to get a good night's sleep after a day of athletic training.


5G

DID YOU KNOW? *Officially, 5G's full name is '5G New Radio', according to 3GPP, the group that governs mobile standards*

HOW IT WILL SUPERCHARGE YOUR LIFE

THIS ULTRAFAST MOBILE INTERNET TAPS INTO UNTOUCHED FREQUENCIES, ENABLING TECHNOLOGY THAT WILL TRANSFORM HOW WE LIVE AND WORK

Words by **Jack Parsons**

Look at the top-left or top-right corner of your phone screen. What does it say? The chances are it reads '4G'. If you visit a city, this might change to '4G LTE'. This means you'll get slightly faster internet. Or if you travel to the countryside, it could say '3G'. Here your video streaming might stutter. But this year, if you're in the right place with the right device, that top corner will say something new: 5G. And nothing will be the same again.

The 'G' stands for 'generation'. 5G is the fifth generation of mobile connectivity, combining pioneering research and the latest technology. But this new generation of network will change more than just how we use our mobile phones. "It will have the same impact as electricity, silicon and steam had in the previous industry revolutions," says Åsa Tamsons, the head of new businesses at Swedish telecom equipment maker Ericsson.

What makes 5G different from previous generations is that it works over higher radio frequencies. While all radio waves travel at the same speed, the wavelength of a particular frequency directly affects how fast it can transmit data. As a rule of thumb, the higher the frequency, the shorter its wavelength and the more bandwidth it has to send information.

The highest frequency 4G uses is 2.6 gigahertz (GHz). The 5G phone towers that are being turned on right now transmit between 3.5GHz and 6GHz. This is why 5G can offer download speeds of up to ten gigabits per second (Gb/s) – ten times what 4G could ever achieve. This will enable you to wirelessly download HD movies in seconds, not minutes.


© Shutterstock

5G's speed will enable AR and VR to be widely used in hospitals

Of course, high-speed mobile internet isn't just about downloads. There's also latency. This is the communication delay on the network, the time lag between you sending a command – tapping a button on a webpage, for example – and the site responding. The less time it takes, the lower the latency. While 4G had a maximum latency of 50 milliseconds, 5G reduces that to just four milliseconds, giving you a near-instantaneous connection every time.

But in the next few years, 5G could get even faster, as internet providers plan to tap into the frequencies way beyond 6GHz. The part of the spectrum between 30GHz and 300GHz is known as the millimetre band for its extremely short wavelengths – just 1-10mm wide. These so-called 'millimetre waves' (or 'mmWaves') have been used for radio astronomy and radar guns in the past. Once we start using mmWaves' blazing-fast bandwidth, 5G will stop feeling like good Wi-Fi and will deliver the benefits it promises.

However, higher frequencies come at a cost. The short wavelengths can't travel long distances and are easily disrupted. Millimetre waves, in particular, require a line of sight with the device they're sending data to and can be blocked by walls or even rain. We'll have to build more antennas in our towns and cities so that we're always close enough to pick up a signal. However, higher frequencies only need small antennas, so rather than high phone towers looming over cityscapes, transmitters will be built into lampposts and traffic lights.

These days, mobile networks aren't just about phone calls. We now have all sorts of bandwidth-demanding devices: tablets that

Innovative infrastructure

The next-gen network is so new, telecoms companies are still experimenting with different ways of delivering it

Mini data centres
Rather than transfer data back and forth to server farms kilometres away, internet providers will build mini data centres into 5G towers to further speed up local data processing.

Indoor antennas
As mmWaves can't pass through concrete, transmitters may even have to be built inside buildings.

Enhanced phone towers
Initially, existing 4G phone towers will be upgraded to use higher frequencies (excluding mmWaves) and offer increased bandwidth.

Swarms of 'small cells'
As 5G can only transmit over short distances, cities will be filled with lots of miniature masts, built into lampposts and traffic lights.

© Adrian Mann


Traffic jams could be consigned to history with 5G networks managing roads

"Rather than high phone towers looming over cityscapes, transmitters will be built into lampposts and traffic lights"


Not just an urban boon, 5G will benefit rural businesses and communities too


5G will enable people to work and stay connected on the go far more easily

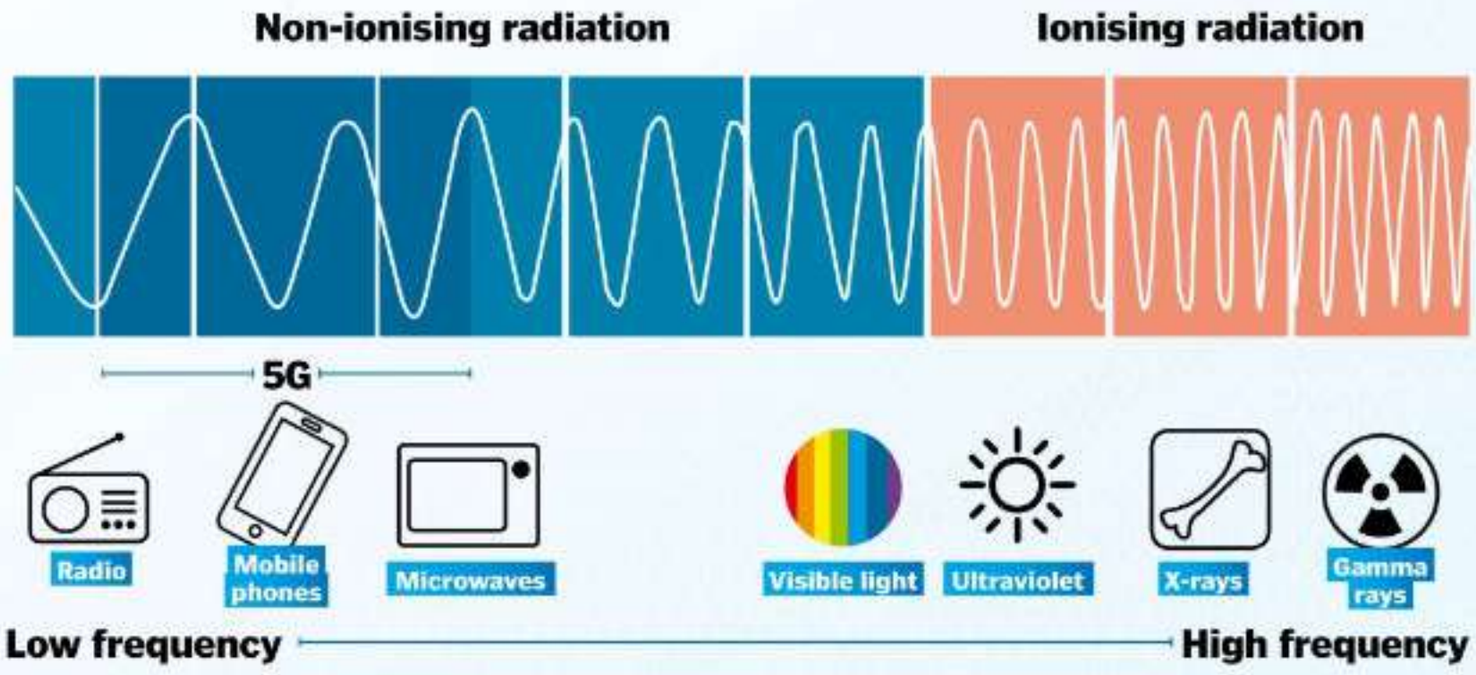
Zapping users with data beams

The higher the frequency, the smaller the antenna you need to detect it. This means you can cram many more into a handset or mast. These can then work together in an array to form a focussed beam of data. Called 'multiple input, multiple output' (MIMO), arrays like this actually already exist. They are used with the faster-than-normal 4G known as LTE. But due to the size of antennas these lower frequencies require, only two or four can fit on both the mast and device. In contrast, it's been estimated that 256 millimetre-wave antennas could be fitted to a phone tower. This jump in scale will be a game-changer. A mega MIMO would be powerful enough to precisely target beams at individual devices. Much more energy-efficient than transmitting a signal across an entire frequency, this would help overcome 5G's biggest weaknesses, allowing signals to cover much larger distances.


A 5G MIMO antenna on display in Shanghai earlier this year

Where does 5G sit on the EM spectrum?

The electromagnetic (EM) spectrum describes all wavelengths, including the visible light we can see and many we can't, like microwaves and x-rays. Radio waves sit at the non-ionising end, with the lowest frequencies and longest wavelengths. Dangerous gamma rays sit at the ionising end, with the highest frequencies and shortest wavelengths, which can damage DNA and cause cancer. While 5G uses higher frequencies than 4G – including millimetre waves – these remain within the 3kHz to 300 GHz radio wave band.



Everyday 5G

While it'll take time for the network to reach its top speeds, 5G will have instant benefits (if you live in the right place)

More energy efficient
Smart software will give telecoms companies better control over networks, so they can make sure there's always enough bandwidth and the system uses less power.

Better business
By having a much faster and more reliable network, businesses – big and small – are expected to benefit hugely from 5G; a 2017 report by PSB Research stated that 89 per cent of businesses expected their productivity to increase.

Smarter classrooms
Augmented reality and virtual reality lessons will be available to students in a 5G-enabled schools, and teachers could deliver lessons remotely in real time, lag-free.

Driving autonomous vehicles
The network will be able to send autonomous vehicles all the data they need – perhaps from smart city road sensors – at a speed that's quick enough to respond to sudden changes, such as a person walking out in the road.

Better connections in crowds
With support for up to 1 million devices per square kilometre, 5G's capacity means a more reliable experience – even in the busiest places at the busiest times.

More reliable
Signals will transfer between phone masts in less than a single millisecond, with no drop-outs.

Superfast downloads
With up to ten times faster speeds, 5G means quicker downloads and the best-quality video stream, every time.

Forget loading times
A maximum latency of just four milliseconds means you'll always get what feels like an instantaneous internet connection.

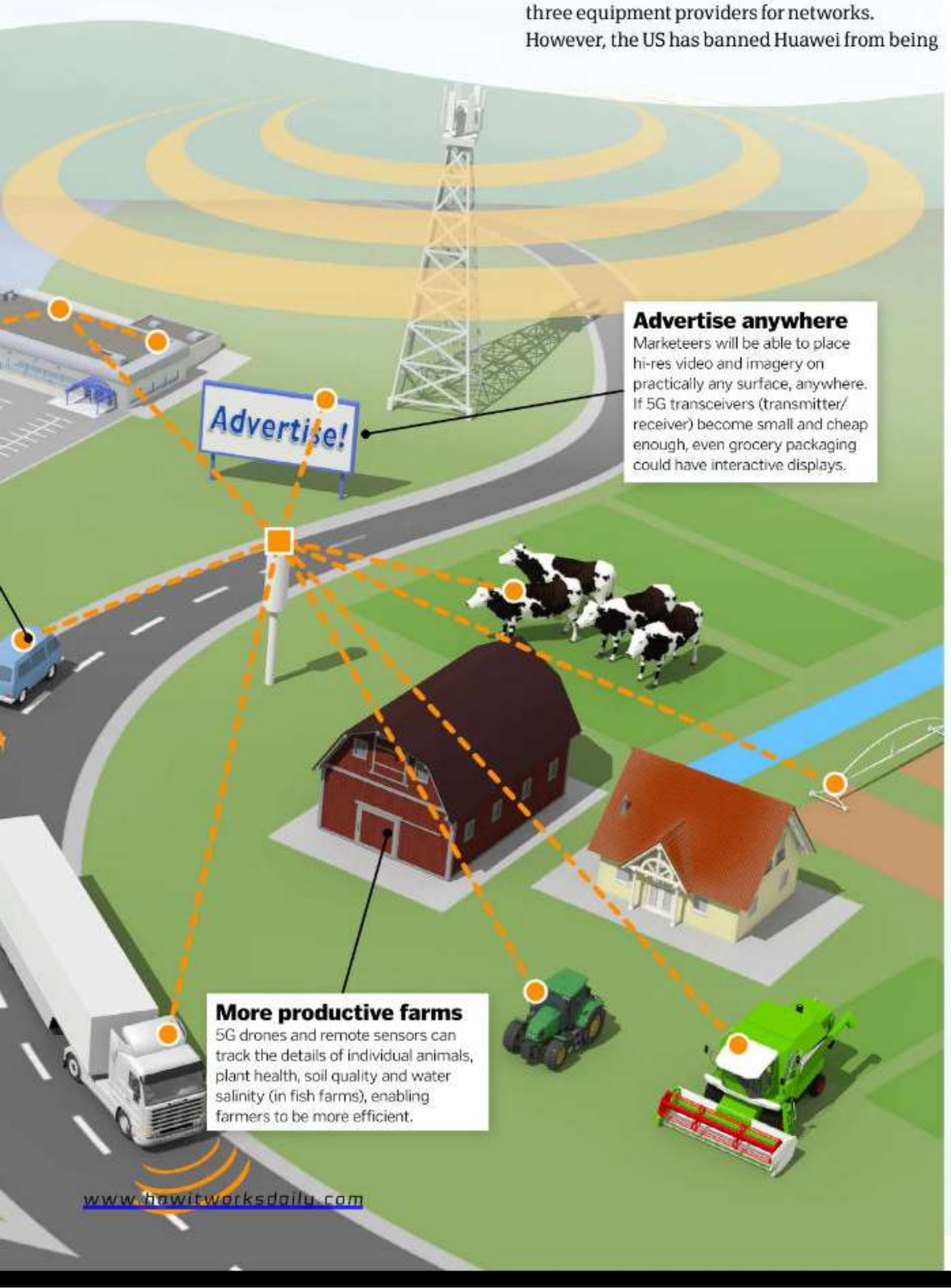
connect to the cloud so people can work on the go, smartwatches that have their own data plans and household gadgets like always-on HD security cameras. This trend is expected to continue, with the world going from 8.4 billion internet-connected devices two years ago to over 20 billion by 2020 – tripling the amount of mobile data we use.

Fortunately, 5G is up to the job. The shorter wavelengths it uses also give it more capacity, meaning the network can handle more information at one time. So while 4G could connect 100,000 devices per square kilometre, the next-gen network will handle 1 million.

Not only is this high capacity future-proof, but it will set the so-called 'internet of things' (IoT) into hyperdrive. Thousands of everyday objects – from your home to your work to the street corner – will be fitted with sensors, collecting, transmitting and sharing data. All of this information can be combined and analysed in the cloud, helping homes, businesses and whole communities make smarter decisions.

This technological leap forward will lead to new products, businesses and even industries, from self-driving cars to artificial intelligence. Experts say 5G could drive an extra $12 trillion of annual sales by 2035. That's about the size of China's entire economy. It's perhaps no surprise then that countries, as well as companies, are racing to embrace 5G.

The first step is to get the infrastructure in place. Nokia, Ericsson and Huawei are the top three equipment providers for networks. However, the US has banned Huawei from being



Advertise anywhere
Marketeers will be able to place hi-res video and imagery on practically any surface, anywhere. If 5G transceivers (transmitter/receiver) become small and cheap enough, even grocery packaging could have interactive displays.

More productive farms
5G drones and remote sensors can track the details of individual animals, plant health, soil quality and water salinity (in fish farms), enabling farmers to be more efficient.

Q&A
Is 5G hazardous to your health?

Dr David Robert Grimes, cancer researcher and physicist, discusses fears over 5G

The UN's International Agency for Research on Cancer (IARC) has classified radio frequency radiation (RFR) – which includes mobile signals – as "possibly carcinogenic". Should we be worried?

This isn't especially worrying, oddly enough. IARC classification is based on the strength of evidence for a particular agent having a cancer risk, not the degree of severity of that risk. RFR is classed as 2B, which effectively means there's no reliable evidence that there's any cancer risk associated with it. IARC's system is rife for confusion, so it's understandable this classification can worry the unwary.

Is there any evidence suggesting mobile phones are linked to tumours?

There really isn't. Firstly, from a biophysics perspective, the radio frequency of radiation used in mobile phones is strictly non-ionising, so we wouldn't expect it to be able to cause the kind of DNA damage that leads to cancer. Secondly, despite rates of phone use going from almost nothing to nigh-on 100 per cent in just over two decades, we're not seeing any evidence of increased brain tumours, which is what you'd expect to see if there was an effect, as we hold phones to our ears for long stints. To take one example of many, the 13-country Interphone study observed no increase in the risk of common brain cancers correlated with phone use. There is simply no epidemiological data that phones are linked to tumours.

5G requires hundreds of transmitter masts, positioned closer to ground level. Does this mean they'll be giving off more radiation?

Not at all. 5G needs more transmitters because it's more easily attenuated by the environment and can't travel as far. To overcome this, you need more transmitters... but it doesn't mean they'll be giving off more radiation.

Why do you think 5G health risks have prompted conspiracy theories?

Anxiety over 5G isn't unique – we've seen similar unfounded panics in the past on everything from vaccination to water fluoridation to mobiles. What's difficult to address is the fact misinformation can perpetuate further and faster than ever before, allowing scaremongering stories to spread.

involved in certain networks, amid allegations its equipment could be used to help Chinese spying. It's a charge the company strenuously denies. Australia has followed the US's lead. Germany is now tightening up its law on telecoms security standards, but the UK has said it's still willing to work with Huawei.

South Korea was the first to roll out 5G nationwide, with all of its leading telecoms companies switching on their new networks in April. Despite being significantly larger, both China and the US aim to achieve the same thing in 2020. Up to 25 cities in the UK will offer 5G by the end of the year, with the first six in May. Switzerland, though, is leading the pack in Europe, rolling out 5G in 227 areas.

Next will come the phones. 5G will need a next-gen modem, so older phones won't support the new speeds. Many top phone makers have committed to making (or have already launched) 5G-ready smartphones. These include Samsung, Huawei, OnePlus, LG, Xiaomi and Oppo.

Initially, 5G will be targeted at businesses, but this will ultimately benefit all of us. Faster speeds and lower latency for businesses will mean faster responses and better services for consumers. The 5G future is coming along faster than you expect.

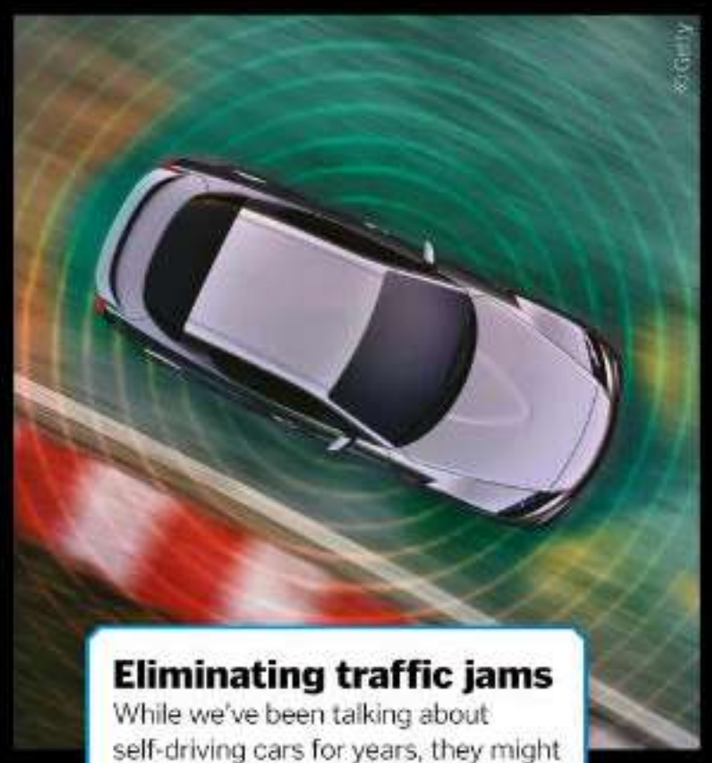
Goodbye broadband?

With 5G, mobile internet promises to beat home broadband speeds, so is it time to cut the cord? You'd have one less bill to pay and it'd be easier to install. Engineers wouldn't need to dig up roads or drill holes in walls to connect homes. Mobile network Three certainly thinks so. It's already selling 5G home routers to do just that, starting in London. You simply plug these into the wall to start accessing up to 100Mb/s speeds. However, established broadband providers think fibre still has a future. They're developing a 'network of networks': smart software that automatically switches you between 4G, 5G and Wi-Fi, depending on which signal is stronger or has more capacity at peak times, so your internet experience is never interrupted.

5G could enhance or ultimately replace your home internet

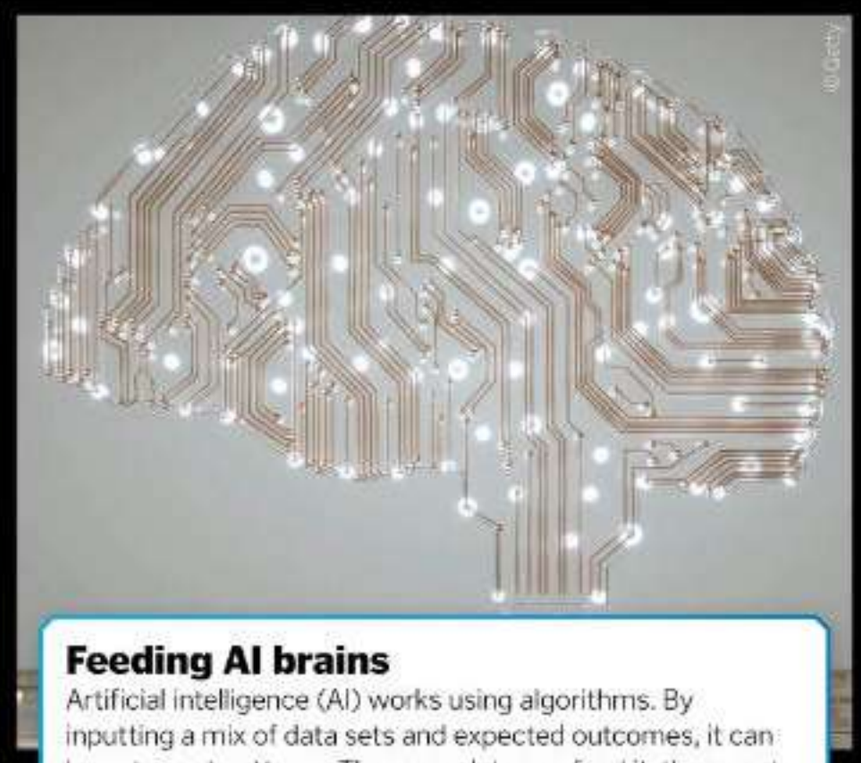
The future of 5G

How 5G will be utilised by businesses and communities



Eliminating traffic jams

While we've been talking about self-driving cars for years, they might finally hit the road with 5G. In the future, autonomous vehicles could be the norm, with traffic managed entirely by 5G systems that can make traffic jams a thing of the past.



Feeding AI brains

Artificial intelligence (AI) works using algorithms. By inputting a mix of data sets and expected outcomes, it can learn to spot patterns. The more data you feed it, the smarter it gets. And 5G will create a massive amount of data. AI may even ultimately manage 5G's incredibly complex networks.

Making drone deliveries

Just as 5G will allow self-driving cars to steer themselves, this technology can do the same for drones, providing them with information, so they can zoom above our heads. This will lead to superhighways in the sky filled with parcel delivery drones and possibly unmanned flying taxis.

The evolution of mobile networks

1940

Also called '0G', the first 'mobile radio telephones' are more like walkie-talkies – only allowing two-way communication – and fill a whole suitcase.

1979

Launching in Japan, 1G allows users to make calls on the go. The phones are chunky, with limited battery, and the signal is poor.
Max speed: 2.4Kb/s

1990

2G's big improvement is to switch from analogue to digital, improving the call quality and making it possible to send data.
Max speed: 64Kb/s

1992

The world's first text message is sent in the UK, reading 'Merry Christmas', from software developer Neil Papworth to his Vodafone boss, Richard Jarvis.

Making AR a reality

Imagine a world where everything looks like a Snapchat filter, overlaid with moving holograms. With increased capacity and lower latency, 5G will make both augmented reality (AR) and virtual reality (VR) more lifelike. Smart glasses can offer next-gen gaming and immersive entertainment on the go.

Building smarter cities

Just as homes are getting more hi-tech – with internet-connected locks, thermostats, lightbulbs and more – so are cities. Sensors connected via 5G will measure everything from a city's energy usage to road traffic to air quality, helping communities make more informed decisions, be safer and better organised.

Remote-control surgery

In March, a Chinese brain surgeon operated on a patient 3,000km away. Guiding a robotic arm, 5G's near-instantaneous connection meant the machine responded in real time to the surgeon's instructions. So-called 'telesurgery' – which allows leading specialists to help wherever they are – will become increasingly popular.

5 FACTS ABOUT

WHAT TO EXPECT FROM 5G PHONES

1 Antennas all over
As millimetre waves are easily disrupted, phones will have to be built in a way so that hands don't cover up the receiver at any time. One solution is to stash tiny antenna arrays in every corner.

2 Longer-lasting batteries
For now, switching between 5G and 4G might drain your battery. But as coverage expands and phones are fitted with more efficient 5G modems, you can actually expect to get something of an energy boost.

3 Bigger price tags
These superfast smartphones will be expensive initially, as will phone plans. But the price will drop over time – just like it did with the launch of 4G.

4 Android only – for now
Samsung, Xiaomi and OnePlus are all selling 5G versions of their flagship handsets. Meanwhile, experts don't expect Apple to launch a 5G iPhone until next year.

5 8K cameras
Chinese smartphone maker Nubia already sells a phone that shoots 48-megapixel pictures and 8K video, so with more bandwidth to play with, it's hard to imagine this trend not catching on.

1998

Finland's Radiolinja launches the first downloadable content sold for mobile phones: the ringtone. These beeping jingles become hugely popular worldwide.

2001

Mobile phones go online with 3G. It isn't that fast, but you can surf the web, send emails, stream music and even make video calls.
Max speed: 2Mb/s

2007

The first iPhone launches. Though it is criticised for not offering 3G, the touchscreen device shows how smart the new 'smartphones' can be.

2009

Debuting in Norway and Sweden, 4G is ten times faster. It makes HD video streaming, gaming and cloud computing possible.
Max speed: 100Mb/s

2018

In December, 3GPP – the organisation that manages mobile standards – agrees what spectrum 5G will use, giving the telecoms industry the green light.

2019

South Korea is the first country to roll out 5G nationwide in April, with the rest of the world not very far behind.
Max speed: 1+Gb/s

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The science of lie detectors

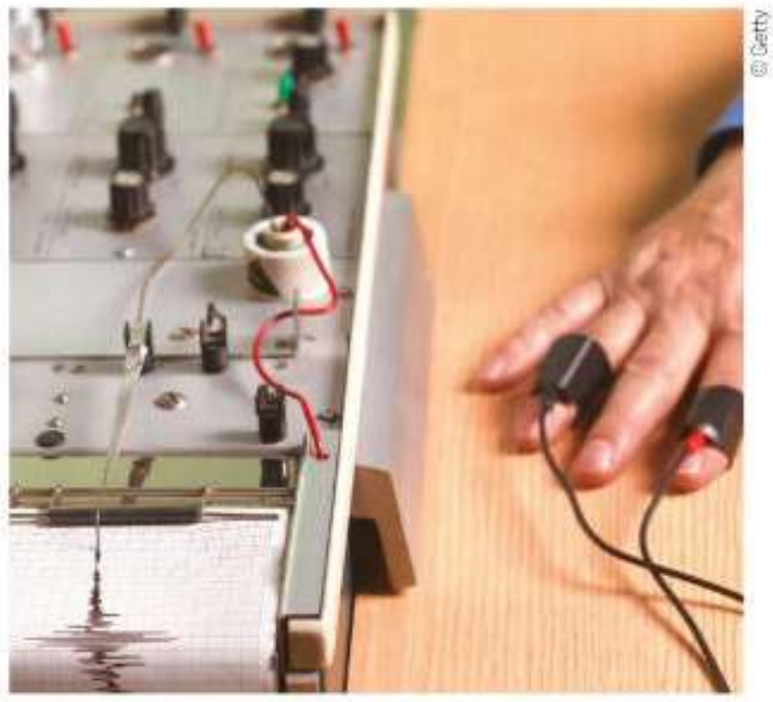
Do polygraphs really reveal the truth, the whole truth and nothing but the truth?

Since the early 1920s 'lie detectors' have been used to evaluate whether or not someone is being deceitful by measuring their physical responses to a series of questions. Elevated blood pressure, a higher breathing rate and increased sweating are all indications that a person may be telling a lie.

A polygraph (lie detector) test, is a method capitalises on these biological signals of lying to sniff out the truth. Hooked-up to a series of sensors, these signs are recorded during the test. The subject is initially asked baseline questions to establish a normal rate of blood pressure, breathing rate and perspiration. The interviewee is then repeatedly asked questions targeted to evaluate whether the answer is deception or truth. The examiner conducting the interview monitors the information coming in from each sensor to see when a spike on the chart occurs – the sign that a deceptive answer may have been given.

This form of lie detection, however, isn't an exact science and has sparked controversy about its legitimacy. A polygraph's ability to collect vital data hasn't been called into question, but how that information is interpreted is debated. Sitting strapped to several wires while an interviewer asks you probing questions is enough to make anyone sweat. Therein lies the main problem with polygraphs. The experience of taking a test can cause enough stress and spikes in blood pressure and respiratory rate to suggest a lie. Similarly, there are ways that people can suppress these changes during an interview.

This doubt in its validity has led to most US and UK courts to ban polygraph data as evidence of guilt or innocence during a trial.



© Getty

'Poly' in ancient Greek means 'many', so a polygraph is named due to the many graphs created at once

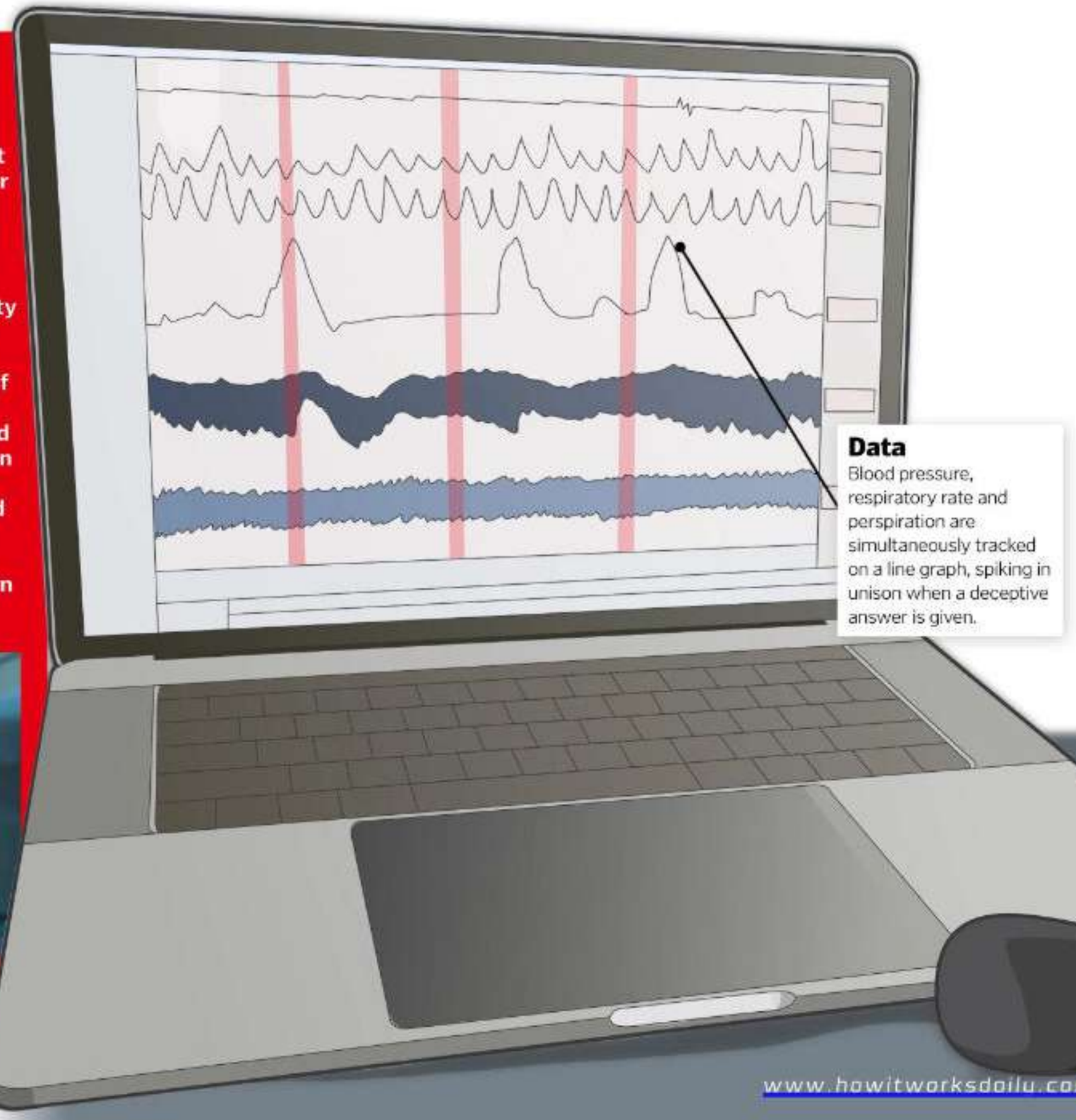
"This doubt in its validity has led to most US and UK courts to ban polygraph data"

Reading the mind

As 'mind-reading' technology continues to advance, could the brain itself be next to face a polygraph test? Brain Computer Interface (BCI) technology is making scientific waves for its ability to open a window into the mind and further our understanding of the body's control centre. By analysing the electrical activity of the brain's neurons, using a wearable device called an electroencephalogram (EEG), researchers may be able to learn if someone is lying by listening to their brains. Earlier this year a study published in the *Journal Of Physics* found that when confronted with images of jewellery items that 'guilty' study participants had 'stolen', the EEG detected spikes in the brain's electrical activity compared to 'non-guilty' participants who were shown the same images.

© iStock

By measuring brain activity scientists could soon decipher when you are being deceptive



Data
Blood pressure, respiratory rate and perspiration are simultaneously tracked on a line graph, spiking in unison when a deceptive answer is given.

Deciphering deception

How a polygraph sniffs out a liar

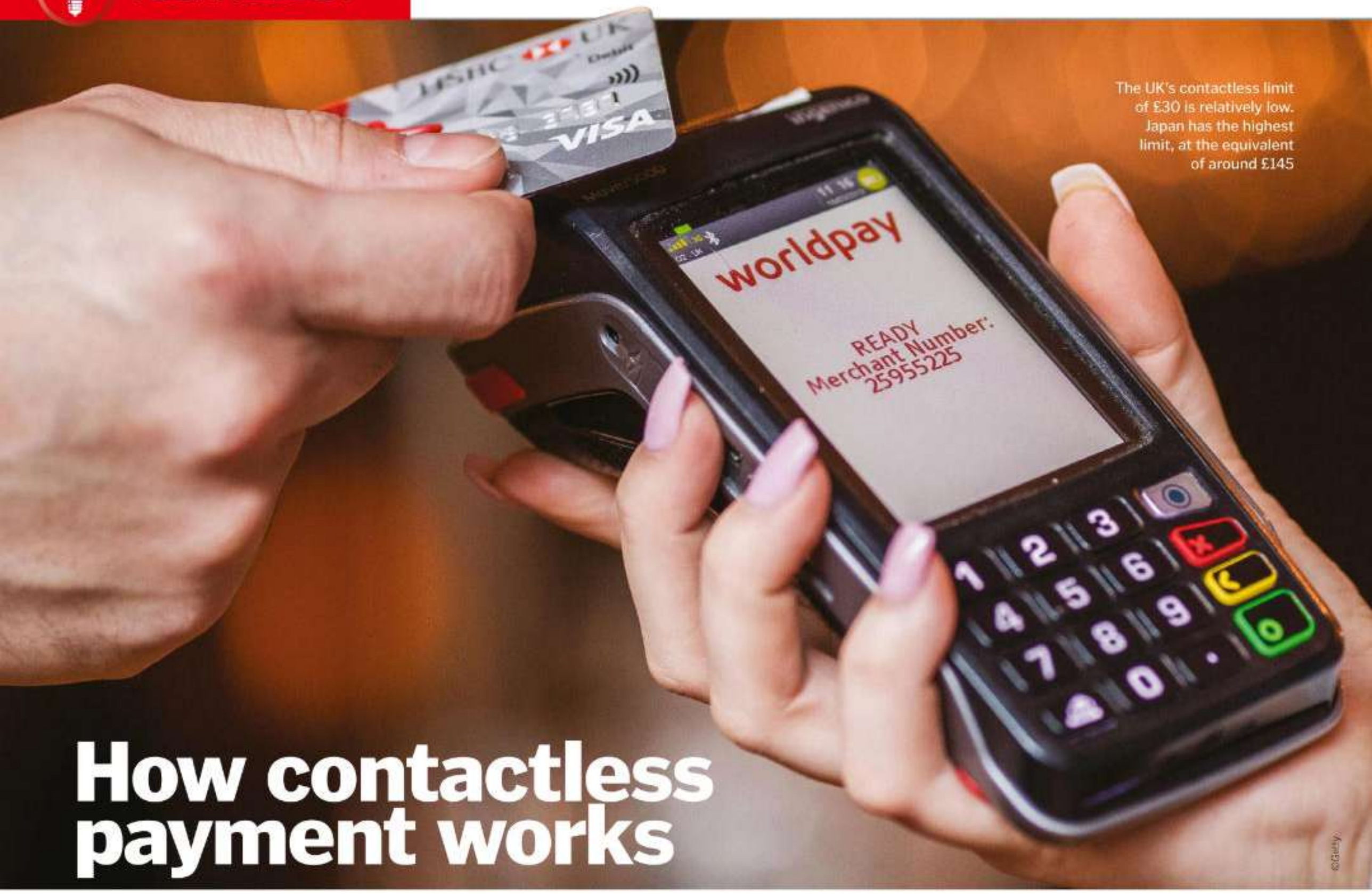
The first 'lie detector' was invented by John Augustus Larson back in 1921

Interrogation
Interviewees are asked a series of predetermined questions to evaluate deception, alongside control questions for comparison.

Breathing rate
Known as a pneumograph, two air-filled tubes are strapped across an interviewee's chest to measure their respiratory rate. During breathing the chest expands and contracts to displace the air in the tube, which is then recorded.

Sweating
Galvanic skin response (GSR) is measured to monitor a person's sweat levels. Sensors are placed on the fingertip to record how electrically conductive they are. More sweat equals more conductivity.

Blood pressure
Using a blood pressure cuff, the sound vibrations of blood passing through vessels displaces the air in the connecting tubes. Changes in the displacement are converted into electrical signals by the use of transducers.



The UK's contactless limit of £30 is relatively low. Japan has the highest limit, at the equivalent of around £145

How contactless payment works

The original aircraft-tracking technology has evolved to change the way we pay

In the UK, when you tap your contactless card you can spend up to £30 in the space of a second. Some people love it, some people are unnerved by it, but have you ever left the till wondering how it can be so straightforward?

These payments use technology called radio frequency identification (RFID). Today there is rising demand for this equipment, with contactless payment being the most common method for in-store card transactions. RFID enables encoded digital data to be transferred via radio waves between two devices. In the case of contactless payment, data is provided between a card and card reader. While they need to be in close proximity to establish a connection, they do not need to come into contact. This form of RFID, used in transmitting data over short distances, is called near-field communication (NFC). NFC technology has gone a step further in speedier payments by enabling people to pay contactlessly using a smartphone.

The recent developments have definitely drawn more awareness to RFID, but when did it first come about? This seemingly modern technology actually emerged before World War II. Sir Robert Watson-Watt is believed to be the first to use radio to obtain data in this manner when he discovered a way to source information about aircraft. His system, radar, was able to detect and reveal limited data about planes, such as its size and whether an aircraft was friend or foe.

The next major progression for RFID was creating affordable commercial applications. Security tags for shops followed, with a simplified early system that only required shopkeepers to switch tags between their two states so that they didn't trigger the door alarm. In 1973, a more complex version was created; an active tag with rewritable memory.

Further advancements in RFID have seen a variety of applications, from tracking transportation of nuclear materials to identifying individual cows for agricultural purposes, come into widespread use.

Avoiding contactless crooks

It can be easy to get lost in the convenience of a contactless lifestyle, forgetting the potential dangers. While it has become easier for you to pay, this new method means that thieves can pickpocket digitally. Using an app that costs just £5 and has been downloaded 1 million times, people can gather the credit card details of anyone within range. This method of stealing data using RFID is called 'skimming'.

However, there are now precautions you can take to enjoy the perks of contactless while keeping your details safe. Wallets like the 'Ekster' wallet are designed to block transmissions, as they encase your cards in a protective aluminium card holder. These work because radio waves cannot travel through all materials. The thin metal layer prevents signals travelling in either direction.

The Ekster wallet has an inbuilt aluminium card holder

The science behind the tap

What goes on in that split second when you pay contactlessly

An intricate design

Built into contactless cards is a small microchip containing account information. A connected copper wire increases the area for detecting signals.

Seeking a connection

Card readers emit radio waves. When a card is placed close enough, the reader is able to send transaction details.

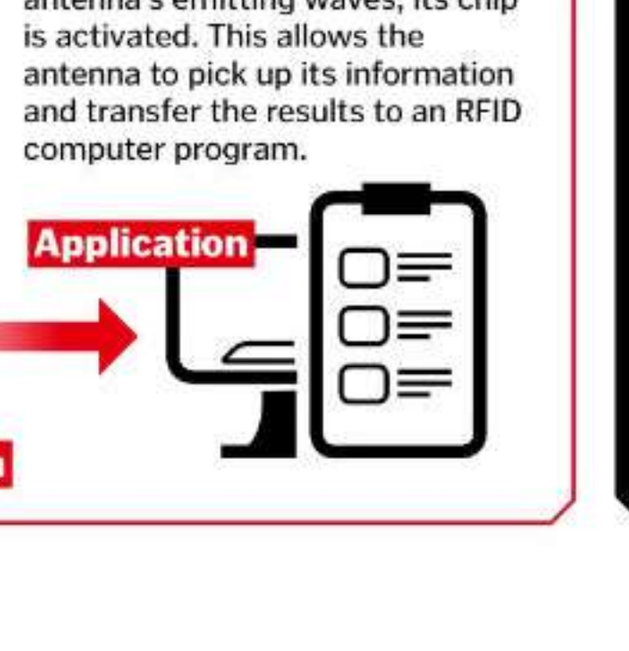
Two-way communication

The card's microchip returns a signal, responding with payment details so the transaction can be processed.

Top-secret coding

The communication takes place using an encrypted language to avoid cloning.

Smart card inventor Ronald Moreno proved that the cards could be used in electronic transactions in 1976



"Thieves are now able to pickpocket, digitally"

Illustrations ©The Art Agency

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RFID around the world

17 million

Contactless journeys are made on London transport each week

30%

More is spent by consumers via contactless payments

Scientists currently use RFID to track bee migrations and populations

0.3 millimetres squared

TO SCALE

The size of the smallest manufactured RFID tag

RFID tags were first invented by a Soviet spy

1/10

Of adults now use cash once a month or less

Edible RFID tags have been created to provide nutritional data

4cm

The maximum range for a contactless card payment

Understanding RFID

An RFID system contains three parts; a tag that is programmed with information, an antenna that scans the tag and an application for the decoded data. The antenna releases radio frequency signals to search for devices and provide the RFID tag with the energy it needs to transfer its data. Using energy from the antenna, and often no batteries, the tag can sometimes be used for decades. When the tag comes into contact with the antenna's emitting waves, its chip is activated. This allows the antenna to pick up its information and transfer the results to an RFID computer program.

A BEGINNER'S GUIDE TO TIME TRAVEL

Learn exactly how Einstein's theory of relativity works, and discover how there's nothing in science that says time travel is impossible

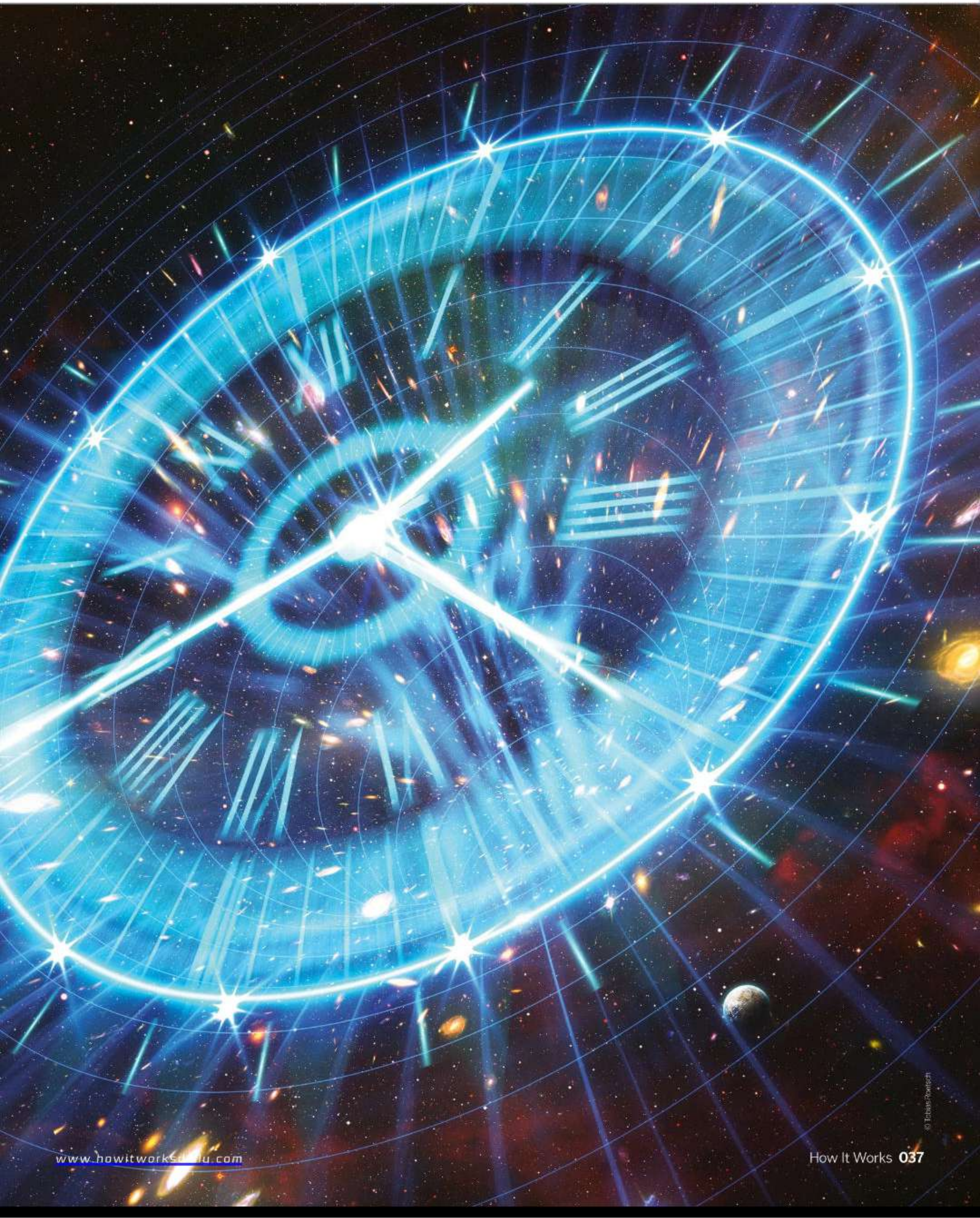
Words by **Andrew May**

Everyone can travel in time. You do it whether you want to or not, at a steady rate of one second per second. You may think there's no similarity to travelling in one of the three spatial dimensions at say, one metre per second. But according to Einstein's theory of relativity, we live in a four-dimensional continuum – spacetime – in which space and time are interchangeable.

Einstein found that the faster you move through space, the slower you move through time – you age more slowly, in other words. One of the key ideas in relativity is that nothing can travel faster than the speed of light – about 300,000 kilometres per second (or one light year per year). But you can get very close to it. If a spaceship was flying at 99 per cent of the speed of light, you'd see it travel a light year of distance in just over a year of time.

That's obvious enough, but now comes the weird part. For astronauts onboard, the journey would take a mere seven weeks. It's a consequence of relativity called time dilation, and in effect it means the astronauts have jumped about ten months into the future.

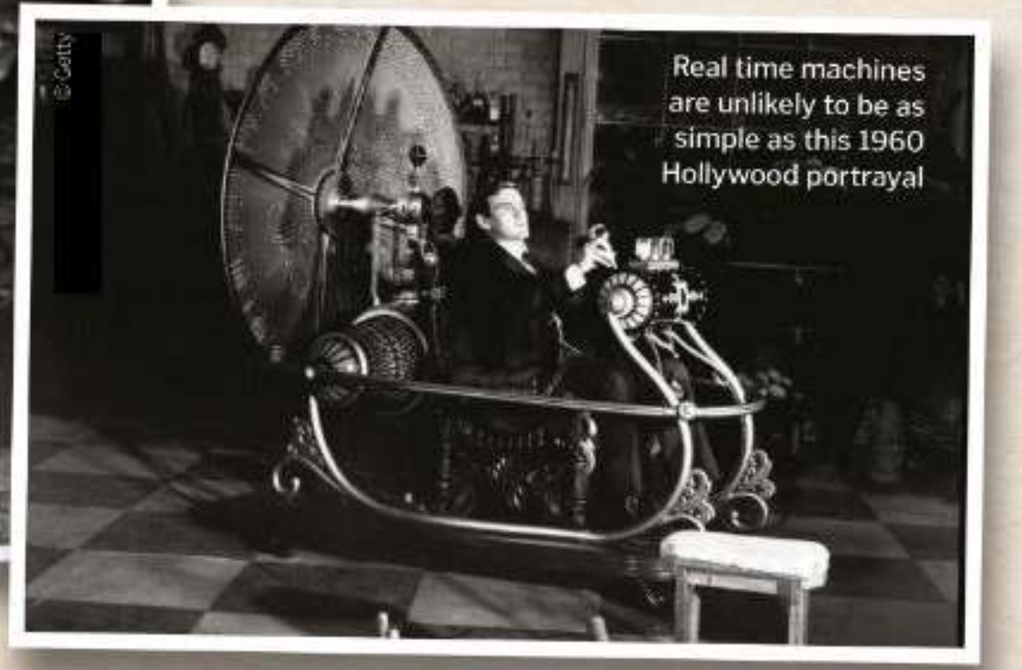
DID YOU KNOW? *Because of the time its light takes to reach us, we see the Sun as it was eight minutes in the past*



Albert Einstein, whose name has become virtually synonymous with relativity

Travelling at high speed isn't the only way to produce time dilation. Einstein showed that gravitational fields produce a similar effect – even the relatively weak field here on the surface of the Earth. We don't notice it, because we spend all our lives here, but 20,000 kilometres higher up gravity is measurably weaker – and time passes more quickly, by about 45 microseconds per day. That's more significant than you might think, because it's the altitude at which GPS satellites orbit the Earth, and their clocks need to be precisely synchronised with ground-based ones for the system to work properly. The satellites have to compensate for time dilation effects due both to their higher altitude and their faster speed. So whenever you use the GPS feature on your smartphone or your car's satnav, there's a tiny element of time travel involved. You and the satellites are travelling into the future at very slightly different rates.

But for more dramatic effects, we need to look at much stronger gravitational fields, such as those around black holes, which can distort spacetime so much that it folds back on itself. The result is a so-called wormhole, a concept that's familiar from sci-fi movies but actually originates in Einstein's theory of relativity. In effect, a wormhole is a shortcut from one point in spacetime to another. You enter one black hole and emerge from another one somewhere else. Unfortunately, it's nothing like as practical



Real time machines are unlikely to be as simple as this 1960 Hollywood portrayal

A BRIEF HISTORY OF TIME TRAVEL

1895

H.G. Wells's novel *The Time Machine* popularises the idea of time as the fourth dimension, through which it might be possible to travel by analogy with the three spatial dimensions.

1905

Einstein's groundbreaking paper on the theory of relativity introduces the idea of time dilation – the first hint that, in real physics as well as sci-fi, time might be interchangeable with space.

1927

The physicist Arthur Eddington first introduces the concept of the 'arrow of time', and its relation to entropy, in his book titled *The Nature Of The Physical World*.

1935

Together with Nathan Rosen, Einstein shows that under certain circumstances it's possible to have a shortcut between two different points in spacetime – a wormhole – even between past and future.

"Everything not forbidden is compulsory"

a means of transport as Hollywood makes it look, because the black hole's gravity would tear you to pieces as you approached it, but it really is possible in theory. And because we're talking about spacetime, not just space, the wormhole's exit could be at an earlier time than its entrance, so you'd end up in the past rather than the future.

Trajectories in spacetime that loop back into the past are given the technical name 'closed timelike curves'. If you search through serious academic journals, you'll find plenty of references to them – far more than you'll find to 'time travel'. But in effect, that's exactly what closed timelike curves are all about.

There's another way to produce a closed timelike curve that doesn't involve anything quite so exotic as a black hole or wormhole: a simple a rotating cylinder made of super-dense material. Called a Tipler cylinder, it's the closest that real-world physics can get to an actual, genuine time machine. But it's not something that's ever likely to be built in practice, so like a wormhole it's more of an academic curiosity than a viable engineering design.

Yet as far-fetched as these things are in practical terms, there's no fundamental scientific reason – that we currently know of – that says they're impossible. That's a thought-provoking situation, because as the physicist Michio Kaku is fond of saying – "everything not forbidden is compulsory". He doesn't mean time travel has to happen everywhere all the time, but that the universe is so vast it ought to happen somewhere at least occasionally. Maybe some super-advanced civilisation in another galaxy knows how to build a working time machine, or perhaps closed timelike curves can even occur naturally under certain rare conditions.

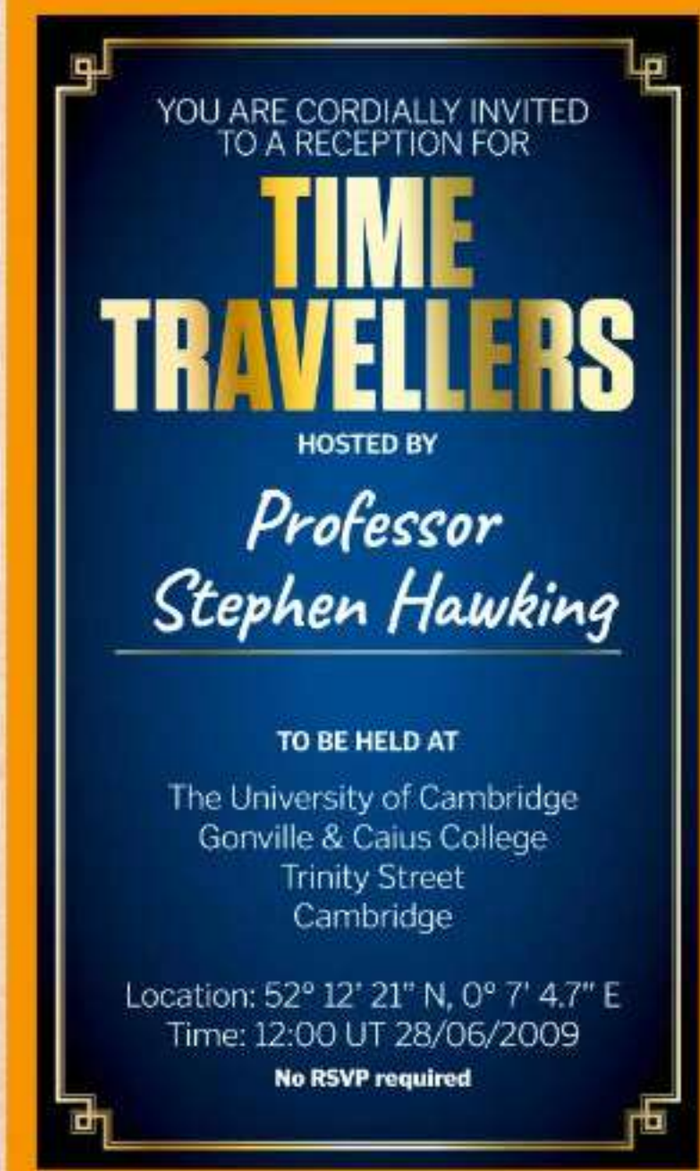
This raises problems of a different kind – not in science or engineering, but in basic logic. If time travel is allowed by the laws of physics, then it's possible to envisage a whole range of paradoxical scenarios. Some of these appear so illogical that it's difficult to imagine that they could ever occur. But if they can't, what's stopping them?

Thoughts like these prompted Stephen Hawking, who was always sceptical about the idea of time travel into the past, to come up with his 'chronology protection conjecture': the notion that some as-yet-unknown law of physics prevents closed timelike curves from happening. But it's only an educated guess, and until it's supported by hard evidence, there's only one conclusion we can come to: time travel is possible.

A PARTY FOR TIME TRAVELLERS

Physicist Stephen Hawking was sceptical about the feasibility of time travel into the past. This wasn't because he'd disproved it, but he was bothered by the logical paradoxes it created. In his 'chronology protection conjecture', he surmised that physicists would eventually discover a flaw in the theory of closed timelike curves that made them impossible.

In 2009 he came up with an amusing way to test this conjecture. Hawking held a champagne party (shown in his Discovery Channel programme) but he only advertised it after it had happened. His reasoning was that, if time machines eventually become practical, someone in the future might read about the party and travel back to attend it. But no one did – Hawking sat through the whole evening on his own. This doesn't prove time travel is impossible, but it does suggest that it never becomes a commonplace occurrence here on Earth.



1941

Two American experimenters, Herbert Ives and G.R. Stilwell, confirm the reality of time dilation by observing fast-moving particles inside a TV-style cathode ray tube.

1974

Physicist Frank Tipler designs the first real time machine (on paper at least). According to the design, a Tipler cylinder would use a string of rotating neutron stars to produce a closed timelike curve.

1992

Stephen Hawking suggests that there might be an undiscovered law of nature that prevents closed timelike curves, therefore preventing time travel into the past from occurring.

2009

Stephen Hawking holds a party for time travellers, which is widely publicised – but only after it has taken place. Unfortunately no time travellers turn up to the party.

IT'S ALL RELATIVE

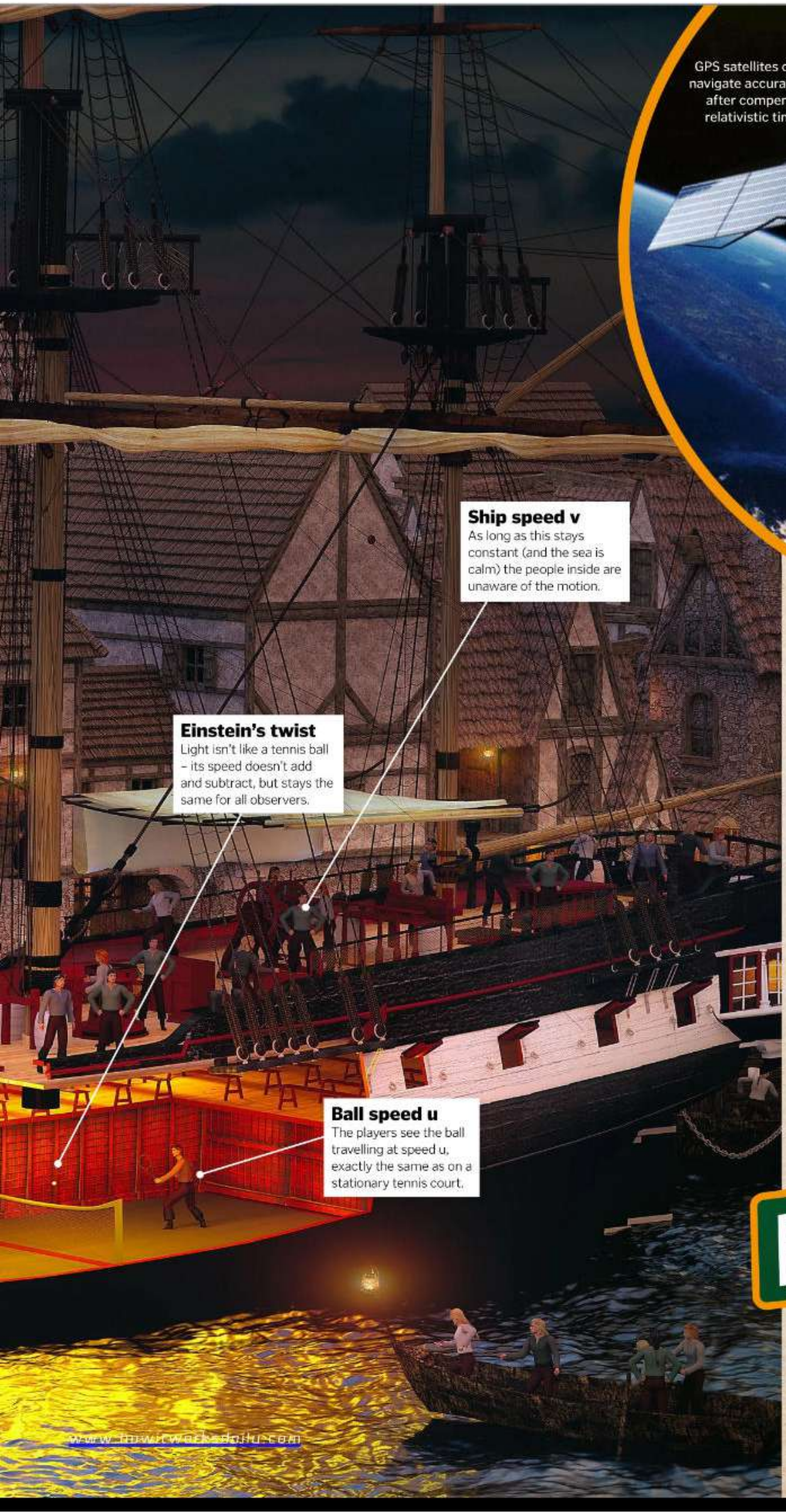
Long before Einstein in 1632, Galileo described the basics of relativity using tennis players on a ship

Galileo's insight
He realised the laws of physics work the same way whether you're stationary or in uniform motion.

Physics experiment
Any experiment on the ship (like this game of tennis) produces the same result as it would on dry land.

View from the quayside
Galileo would see the ball travelling at speed v + u (left to right) or v – u (right to left).

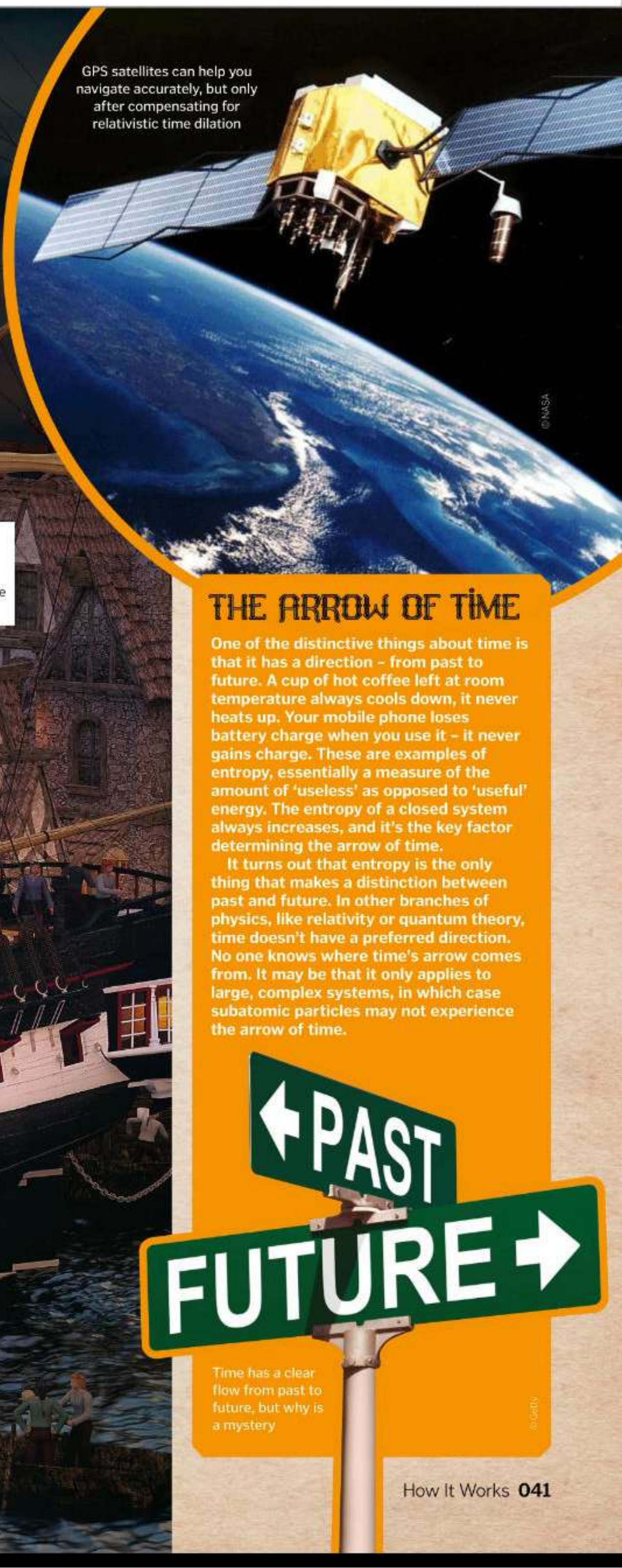
DID YOU KNOW? *The electrons in old-style TV tubes were so fast-moving that relativity had to be taken into account*



Ship speed v
As long as this stays constant (and the sea is calm) the people inside are unaware of the motion.

Einstein's twist
Light isn't like a tennis ball – its speed doesn't add and subtract, but stays the same for all observers.

Ball speed u
The players see the ball travelling at speed u, exactly the same as on a stationary tennis court.



GPS satellites can help you navigate accurately, but only after compensating for relativistic time dilation

© NASA

THE ARROW OF TIME

One of the distinctive things about time is that it has a direction – from past to future. A cup of hot coffee left at room temperature always cools down, it never heats up. Your mobile phone loses battery charge when you use it – it never gains charge. These are examples of entropy, essentially a measure of the amount of 'useless' as opposed to 'useful' energy. The entropy of a closed system always increases, and it's the key factor determining the arrow of time.

It turns out that entropy is the only thing that makes a distinction between past and future. In other branches of physics, like relativity or quantum theory, time doesn't have a preferred direction. No one knows where time's arrow comes from. It may be that it only applies to large, complex systems, in which case subatomic particles may not experience the arrow of time.

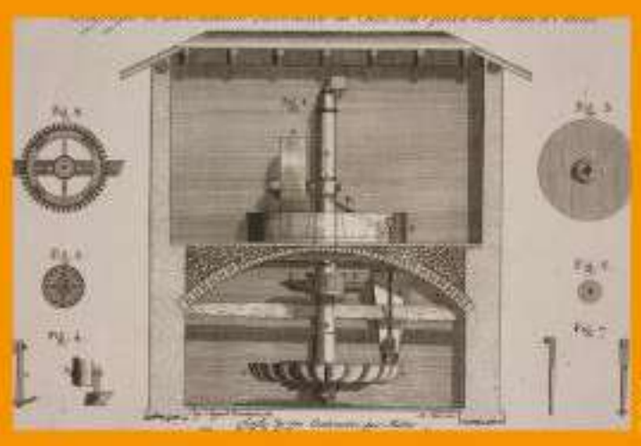
Time has a clear flow from past to future, but why is a mystery

TIME TRAVEL PARADOX

If it's possible to travel back into the past – even theoretically – it raises a number of brain-twisting paradoxes that even scientists and philosophers find extremely perplexing.

Killing Hitler
Hitler was one of the most evil people in history, causing untold death and misery. A time traveller might decide to go back and kill him in his infancy. If they succeeded, future history books wouldn't even mention Hitler – so what motivation would the time traveller have for going back in time and killing him?

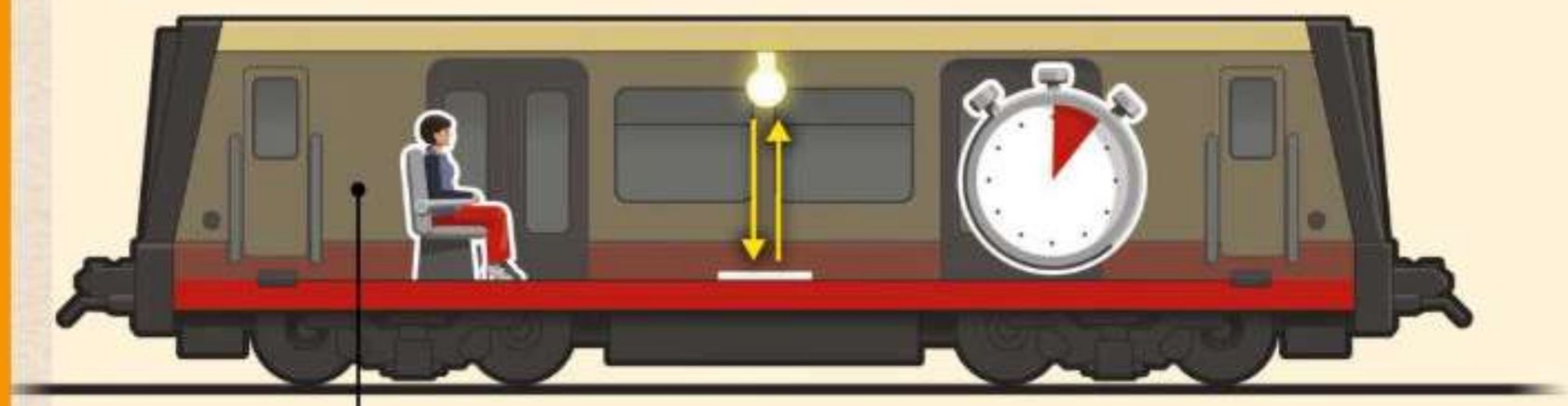
Killing your grandfather
Instead of killing a young Hitler, you might, by accident, kill one of your own ancestors when they were very young. But then you would never be born, so you couldn't travel back in time to kill them, so you would be born after all, and so on...



A closed loop
Suppose the plans for a time machine suddenly appear from thin air on your desk. You spend a few days building it, then use it to send the plans back to your earlier self. But where did those plans originate? Nowhere – they're just looping round and round in time.

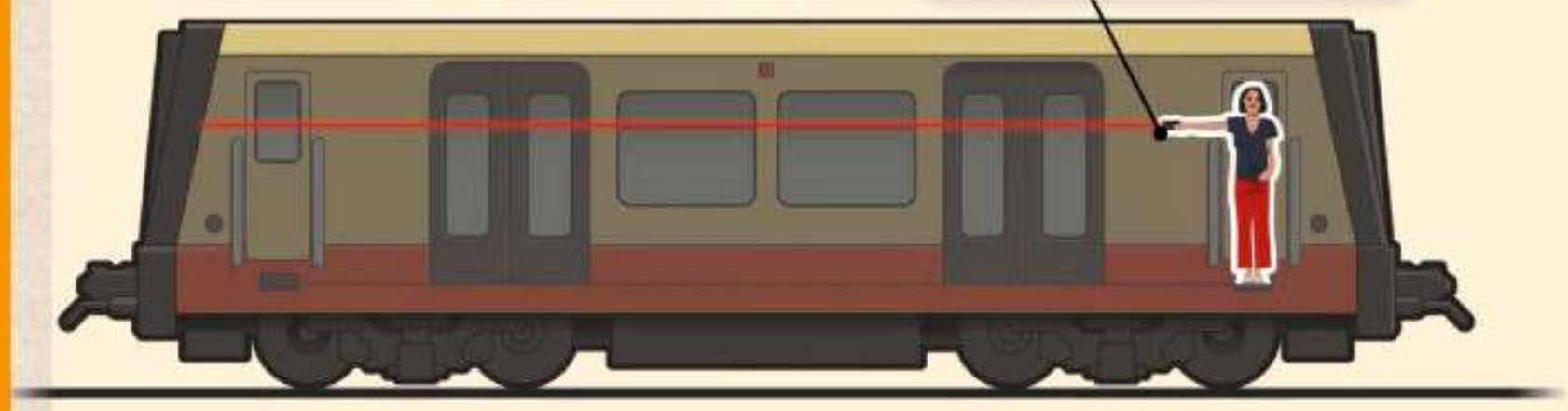
THE RELATIVITY OF TIME AND SPACE

The fact that all observers measure the same speed of light has some odd consequences



1 Experiment inside a moving train
Alice measures the time a beam of light takes to travel from the ceiling of the carriage to a mirror on the floor, and then back to the ceiling.

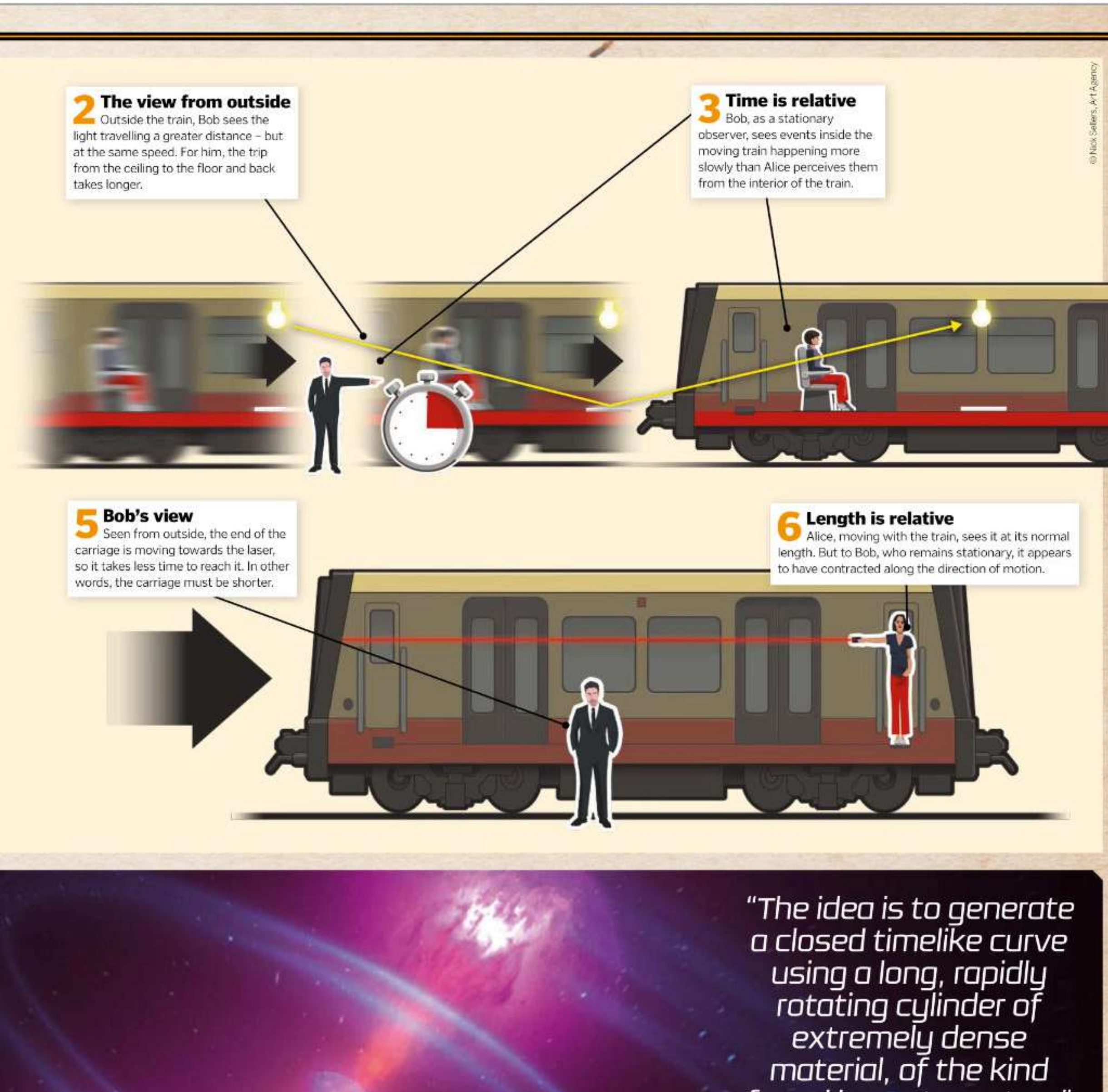
4 Another experiment
Alice uses a laser rangefinder to measure the carriage length. This is the time the beam takes to travel to the end and back, divided by the speed of light.



TIPLER CYLINDER

In 1974, the eminently respectable journal *Physical Review* published a paper by Frank Tipler that contained the first scientifically feasible design for a time machine. Sadly, although it doesn't break any laws of physics, Tipler's machine poses so many engineering challenges it would be impossible to build one in practice.

The idea is to generate a closed timelike curve using a long, rapidly rotating cylinder of extremely dense material, of the kind found in neutron stars. These aren't quite as extreme as black holes, but they're still not easy things to manipulate. And to make a cylinder of the necessary length, at least ten of them would need to be brought together and lined up. This means that, just like wormholes, Tipler cylinders fall into the 'possible in theory, but impossible in practice' category.



"The idea is to generate a closed timelike curve using a long, rapidly rotating cylinder of extremely dense material, of the kind found in neutron stars"

An artist's impression of a pair of neutron stars – a Tipler cylinder requires at least ten

What are eye floaters?

Discover what causes these optical oddities

Gazing up at clear blue skies can sometimes be interrupted by what appear to be bouncing squiggles of dust that evade our attempts to focus on them. These mysterious floaters are not specks on the surface of our eyes, but rather a part of the eye itself.

Filling the gap between the lens and retina is a pool of jelly-like fluid called the vitreous humour. As we age this eye jelly naturally begins to degrade and very slowly liquify. During this lifelong process, tiny 'clumps' break away and surf in the surrounding jelly. Known as vitreous floaters, they are most common in older people and those who are short-sighted.

Often unnoticed in day-to-day life, these floaters usually make an appearance when we stare at a bright, blank canvas, such as a blue sky. As light enters the eye, these vitreous floaters obscure the light and cast a shadow over the light-detecting cells at the back of the eyes – the retina. When this communicates with the brain via the optic nerve, tiny lines of light are missing, so we see the floaters as shadows.

This biological shadow-puppet show is no cause for alarm in those that witness it. However, should the group of squiggles and wiggles increase dramatically then a trip to the optician may be necessary. This could potentially be a sign of retinal detachment, where the thin cellular lining tears and peels away from supporting blood cells, which can cause permanent sight damage.

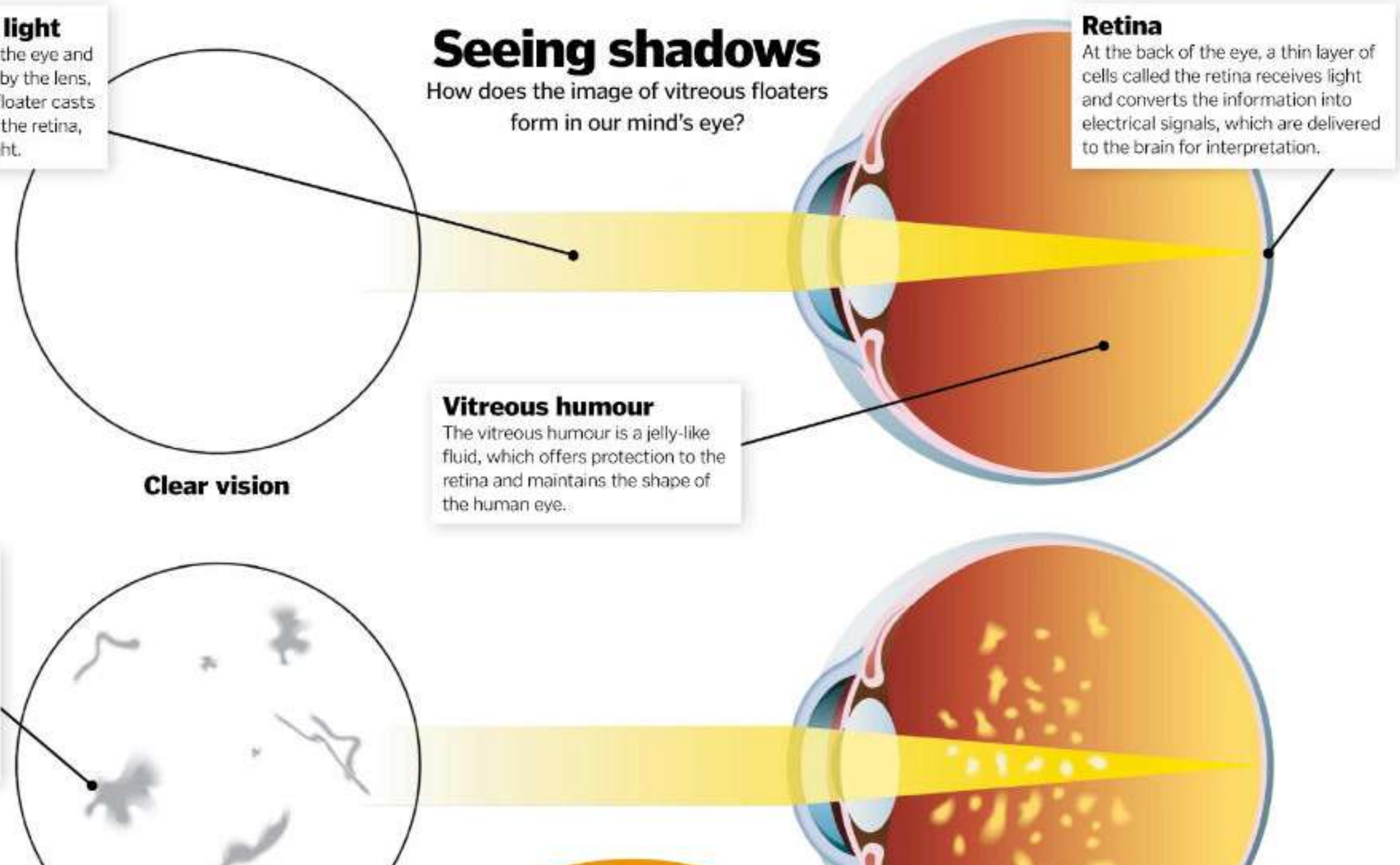
Seeing stars can be the result of a traumatic blow to the head or increased pressure on the eyeball

Seeing stars

Eye floaters aren't the only oddities that can enter into our field of vision. Comically seen in Tom and Jerry sketches, a blow to the head can leave the receiver counting stars. The reason for this temporary light show is a miscommunication between the brain and the retina. The occipital lobe (the area of the brain where vision is processed) is located at the back of the head. A blow here can cause this area of the brain to misinterpret electrical signals as light. Similarly, in the eye a knock can cause the vitreous humour to hit the retina, sending out signals of light.

Seeing shadows

How does the image of vitreous floaters form in our mind's eye?



Retinal imaging can reveal the condition of the eye's retina and identify the likelihood of retinal detachment

50TH ANNIVERSARY SPIRIT OF CONCORDE CHRONOGRAPH WATCH

REAR OF THE CASING:

Reverse etched with Spirit of Concorde logo and Concorde model reference numbers

PRESENTATION CASE:

Comes with a custom-designed presentation case

KEY DETAILS

EVENT: The 50th anniversary of Concorde's first flight.

OFFICIAL: Officially licensed by Spirit of Concorde Ltd.

HIGH SPECIFICATION: Intended as a collectors' timepiece, this watch will feature three precision chronograph dials, durable stainless steel casing and strap, and a dark blue cockpit aviation style face.

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A prestigious tribute to a unique aviation icon, this heirloom watch will feature a rugged stainless steel casing and strap. Inspired by the high-tech cockpit design of Concorde, the dial will showcase three chronograph dials with minute and second stop-start function, date display and a Spirit of Concorde logo. The precision Quartz movement watch's reverse will be etched with a further Spirit of Concorde logo and Concorde model reference numbers.

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DID YOU KNOW? 1.43% of samples tested by the WADA in 2017 showed adverse results connected with doping

HOW TO CATCH A SPORTS CHEAT

Uncover the methods used by cheating athletes and the scientists who rise to stop them

Words by **James Horton**

In 1954, physician John Ziegler was meeting with a colleague from the Soviet Union. Both scientists were in the employ of their respective country's weightlifting teams, and at that moment in time the Soviets were ahead. They were just too strong. Ziegler pressed for an explanation, and his Soviet counterpart offered him one – his team had been using testosterone to build muscle mass, and the results spoke for themselves. Anabolic steroids had not yet been banned in professional competition, so Ziegler swiftly returned to his team and shared his discovery. Soon the US team, like the Soviets, were pumped full of doping agents.

This was an arms race in a very literal sense. But the US and the Soviet Union weren't the only two players. All over the world, in different sports, athletes turned to drugs to enhance their performance. The tide of doping would lead to one cyclist saying that all he had to do was "follow the trail of empty syringes and dope wrappers" to stay with the pack during a race. Natural prowess had been shunned for artificial gains. The anti-doping agencies had to fight back; they needed new tests, and quickly.

Luckily the tests arrived. Today, the World Anti-Doping Agency (WADA) uses around 30 state-of-the-art laboratories that are equipped to screen for hundreds of doping compounds. They're able to detect anabolic steroids, stimulants, diuretics, narcotics, alcohol, synthetic oxygen carriers and more. Most of these tests are conducted using an athlete's urine. Blood is also screened, but urine is easy to collect – an athlete simply urinates into two containers: an 'A' and a 'B' sample, which is taken to the laboratory. The B sample (the back-up) can be stored in the freezer for over a decade if required, while the A sample is opened for screening.

Urine screening can be completed just 24 hours after starting the analysis

To prevent tampering with the urine during transit, the containers must be broken to be opened. If this occurs before it arrives in the lab, the B sample will have to be used. Once open, the urine's concentration is calculated before it is filtered, removing the unnecessary components of the liquid and leaving behind only the compounds the researchers are interested in assessing. A piece of equipment known as a mass spectrometer – which cleverly calculates the mass of compounds whizzing through it – is able to identify the majority of banned doping products if they are present.

For the trickier compounds, scientists use antibodies to bind to the prohibited compounds, which become visible on gels if they are in the sample. More still can be identified using a method known as SDS-PAGE, which shows the size of proteins as they are run through a gel membrane. With all three techniques together, there is not much the scientists cannot find.

However, despite the technologies now available to governing bodies, the dopers haven't been fully deterred. Some still try to circumvent the tests, sometimes through ingenious methods. They attempt to use 'masking compounds', which disguise other performance-enhancing drugs from detection, and inject themselves with doping agents that quickly break down and are hard to capture in time. The hormone that controls the production of red blood cells, erythropoietin, falls into this latter category. Synthetically created erythropoietin has a half life of just hours, but in that time it can stimulate the production of red blood cells that lasts for weeks.

To combat issues such as this, the UK Anti-Doping agency (UKAD) has implemented the Biological Passport programme. This involves the periodic collection and screening of an athlete's blood and urine, which are then recorded over time. If the athlete suddenly has a spike in a certain compound, the scientists can then begin to probe into the reason why. Has the athlete changed their training regime, or is something more sinister afoot?

Reinforced with the Biological Passport, dopers in regulated sports are very hard-pressed when trying to cheat.

But the anti-doping agencies of the world cannot relax. WADA's list of banned substances is updated each year, and dopers are constantly trying to find loopholes. Perhaps even more worrying are the new doping techniques appearing on the horizon. 'Neurodoping' has made headlines, as individuals voluntary electrocute parts of their brain in a bid to stimulate neurons. Some believe this may improve academic or athletic performance, but evidence for this has so far been lacking.

Gene doping, however, may represent a serious risk for the future. Despite gene editing still being poorly tested and highly dangerous in humans, WADA has already added gene-doping agents onto its list of banned substances. For a doper, the appeal is obvious. Why inject yourself with a booster of a banned protein molecule when you can have your DNA produce more of the molecule itself? If we do succeed in developing effective gene-editing technologies to treat disease in the future, dopers may manipulate the technology for their nefarious needs. But you can be sure that the anti-doping laboratories will be there to catch them.

© UKAD - King's College London

The stripping of Ben Johnson's Olympic gold for doping gave rise to one of the biggest scandals in sporting history

© K3/Getty

Twisting medication into doping agents

Although designed to help the sick, many medicines are abused as performance-enhancing drugs

Testosterone

What it's for: Replacing the male sex hormone following testicular-removal or in older men.

Why it's banned: Testosterone is important for muscle and bone development. It's been linked to weaker skeleto-muscular systems and feminisation when natural production drops or stops in males. When taken on top of normal bodily production, synthetic testosterone can drive muscle growth above natural levels, unfairly boosting an athlete's strength gain.

Ephedrine

What it's for: Alleviating nasal congestion and the tightening of airways caused by asthma.

Why it's banned: Stimulants such as ephedrine are appealing to doping athletes for two reasons. They can aid an athlete in boosting weight loss and they also boost available energy for the athlete during competition, partly by raising blood pressure and increasing blood supply.

Diuretics

What it's for: Lowering blood pressure, reducing tissue swelling and eliminating kidney stones.

Why it's banned: Sometimes known as 'water pills', diuretics affect kidney function and result in increased urine output. Athletes – who often have their urine screened for doping agents – can take diuretics to dilute their sample below detectable levels. Other athletes, such as boxers, use them to artificially lose water weight before a weigh-in.

Beta blockers

What it's for: Regulating high blood pressure in individuals at risk of cardiac disease.

Why it's banned: Beta blockers work to lower blood pressure by blocking the action of adrenaline – a hormone that increases blood circulation. This results in relaxed blood vessels and a slower heart rate, lowering the anxiety of athletes competing in sports such as shooting and archery, offering them a steadier hand.

Tamoxifen

What it's for: Treating breast cancer in men and women by blocking oestrogen receptors.

Why it's banned: When an athlete dopes on testosterone, their body responds by increasing the amount of oestrogen production – a female sex hormone – which can result in breast growth. Blocking oestrogen receptors with tamoxifen can help to keep this side-effect at bay, helping an athlete to continue cheating through testosterone doping.

Many exercise enthusiasts turn to supplements and doping to chase extreme and sometimes unrealistic goals

UKAD scientists at the King's College laboratory, London, can test for almost any banned substance

UKAD has been involved in programmes on the benefits of fair play for children and young athletes

Encouraging fair play

Testing athletes is incredibly important to ensure fair play, but another element in combating the use of doping agents in sport is through education. Since its inception in 2009, UK Anti-Doping has launched initiatives, starting with young children in primary schools through to teenagers, in a bid to inform about the risks of foul play and the benefits of fair play. The agency hopes to guide younger children into bonding with one another through fair competition and education in sportsmanship. Older children are also being educated on proper nutrition and the severe health risks involved in doping, encouraging them to not cut corners when chasing their first gold trophy or when training towards achieving their perfect physique.

Blood doping

How athletes can artificially increase their red blood cell count to improve their performance

Deposit
The athlete has at least half a litre withdrawn weeks before a competition. Their body will naturally restore the lost red blood cells.

Why more blood
Red blood cells contain haemoglobin, the molecule responsible for carrying oxygen around the body. By increasing their red blood cell count, endurance athletes can keep their muscles supplied with oxygen more easily.

Separation
A piece of equipment known as a centrifuge then spins the blood at high speeds, forcing the red blood cells to the bottom of the tubes.

Plasma
The heavy, oxygen-laden red blood cells clump at the bottom of the tubes, while the remaining liquid is drawn off and returned to the athlete.

Increasing supply
Athletes increase their blood cell count either by transfusion or by injecting the hormone erythropoietin, which instructs the body to increase red blood cell production.

"Our job is to catch the people who are cheating, but it's also to protect the people who aren't"

Timeline

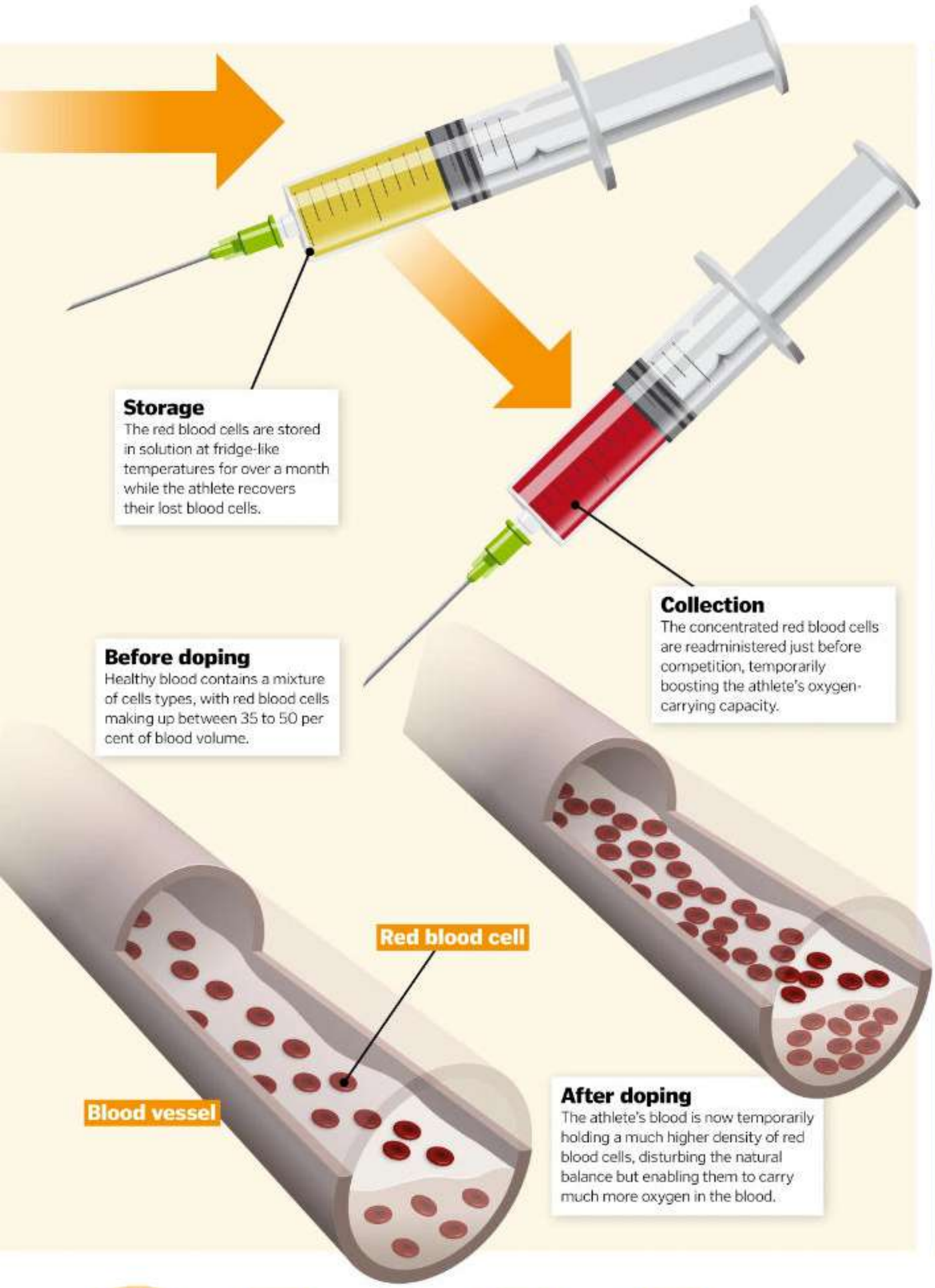
c. 700 BCE
At the ancient Greek Olympic Games, athletes are encouraged to consume sheep testicles, which contain testosterone, as a means of boosting strength.

1904
Marathon-runner Thomas Hicks receives two injections containing the stimulant strychnine (plus some brandy) from his trainer during the race itself. Although extremely dangerous, he goes on to take home the gold.

1928
The International Association of Athletics Federations (IAAF) becomes the first sporting body to ban the use of doping agents for enhancing performance. The IAAF, however, is limited in its ability to enforce the new ruling. Instead it relies mostly on an honesty policy from athletes.

1954
A physician for the US weightlifting team learns that the Soviet Union team has been using testosterone to boost performance. The US team begins using anabolic steroids soon after.

1960
Danish cyclist Knud Enemark Jensen dies during the Rome Olympic Games after taking amphetamine – a stimulant – and Roniacol, a blood vessel dilator.



Storage
The red blood cells are stored in solution at fridge-like temperatures for over a month while the athlete recovers their lost blood cells.

Collection
The concentrated red blood cells are readministered just before competition, temporarily boosting the athlete's oxygen-carrying capacity.

Before doping
Healthy blood contains a mixture of cells types, with red blood cells making up between 35 to 50 per cent of blood volume.

Red blood cell

Blood vessel

After doping
The athlete's blood is now temporarily holding a much higher density of red blood cells, disturbing the natural balance but enabling them to carry much more oxygen in the blood.

Q&A Finding foul play

We speak with Dr Alan Brailsford, head of UK Anti-Doping's laboratory

How many athletes' samples are analysed in the lab every week?
It can vary a lot depending on what sporting events are happening. The summer tends to be quieter, but you can get big events that cause a spike in the number of samples. There's a bit of fluctuation, [but] on average we look at between 200 to 250 samples every week of blood and urine – most of that will be urine. Overall last year we screened around 13,000 samples.

Certain compounds have narrow detection windows. Does this make them the hardest to track?
They do present a challenge, and that's one reason why our work is helped by UKAD's intelligent testing, which looks at the most likely time athletes are going to dope. It'll look at an athlete's training and competition schedule and ask, if you were a doper, when would be the most likely time to take it? So while we may have a narrow window, we can maximise our opportunity by selecting the best time to test. The lab's job then is to work on extending the detection window.

Has working in this field reduced your ability to enjoy competitive sport?
I haven't grown cynical in any way. I don't watch sport with a cynical eye because I know the vast majority of results come back negative and the vast majority of athletes are clean. Our job is to catch the people who are cheating, but it's also to protect the people who aren't and create a fair sport.

1964
Anabolic steroid use becomes ubiquitous at the Olympic Games and in other sports, including bodybuilding.

1966
Drug testing begins for the first time at the European Athletics Championships, held in Budapest, Hungary.

1976
The first test to reliably detect anabolic steroids is developed, enabling governing bodies to ban these substances in future Olympic Games.

1988
100m sprint Olympic champion Ben Johnson is stripped of his gold medal for doping. His prize is handed over to runner-up Carl Lewis, who keeps the medal despite also failing a drug test.

2009
The Athlete Biological Passport programme is launched. An athlete's biological marker information can now be tracked over time, allowing investigators to spot the introduction of doping agents.

2012
Seven-time Tour de France-winning cyclist Lance Armstrong is stripped of all titles received since 1998 after drug and blood doping.

2015
Russian athletes are banned from international competitions after evidence emerges of state-sponsored doping cover-ups.

Keeping cold to live forever

Cryonic preservation relies on the science of the future to cure disease and even cheat death

Preserved bodies are stored together in special 'sleeping bags', in this supercooled container

© Getty

The concept of death is difficult and frightening for many, and the search for immortality dates back centuries. From alchemy and the elixir of life to spending eternity as a cyborg, people have dreamed up numerous schemes for evading the inevitable. One approach that claims to have a scientific foundation is cryonics – the preservation of human bodies by freezing or deep cooling (known as vitrification).

Cryonics takes place after a person is legally dead. Their body or head is frozen and stored indefinitely in a chamber, in the hope that scientists in the future will discover ways of bringing them back to life, reversing any damage caused by the preservation process and curing the disease or condition that caused their death. Cryonicists believe that, as long as death was not caused by trauma and the brain remains intact, technology yet to be invented will allow full revival; suggestions for this future technology include cloning, nanomedicine and copying the mind onto a computer.

Storing frozen bodies was first proposed in 1962 in Robert Ettinger's book *The Prospect Of Immortality*. In 1967 Dr James Bedford, a retired psychology professor, became the first person to be cryonically frozen. Since then around 400 people have joined him in suspension, and it's estimated that 3,000 people around the world have plans to be frozen and stored rather than buried or cremated. Four facilities offer cryonic preservation – one in Russia and three in the US.

Despite a number of fierce supporters, cryonics is largely regarded as a pseudoscience, with the practice denounced by the majority of the scientific community and facilities accused of giving false hope.

"Their body or head is frozen and stored indefinitely in a chamber"

Keeping cool

While the feasibility of cryonics is debated, cryopreservation – preserving cells, blood and tissue by cooling them to extreme temperatures – is an established process that has many medical and veterinary applications. Frozen sperm cells were first successfully thawed and used for IVF in 1954, and egg cells, sperm and embryos can now be stored for numerous years to offer reproductive options to those undergoing cancer treatment or sterilisation.

Organs used in transplants must be kept refrigerated while they're transported between the donor and the recipient. To date only a handful of rat and rabbit organs have been successfully frozen, thawed and transplanted, as large tissues are easily damaged when crystals form during freezing, but it's hoped that future advances in cryopreservation will allow human organs to be stored for longer. Donated organs currently remain viable for just a few hours; freezing would mean they could be stored for much longer, reducing transplant waiting lists.

© Getty

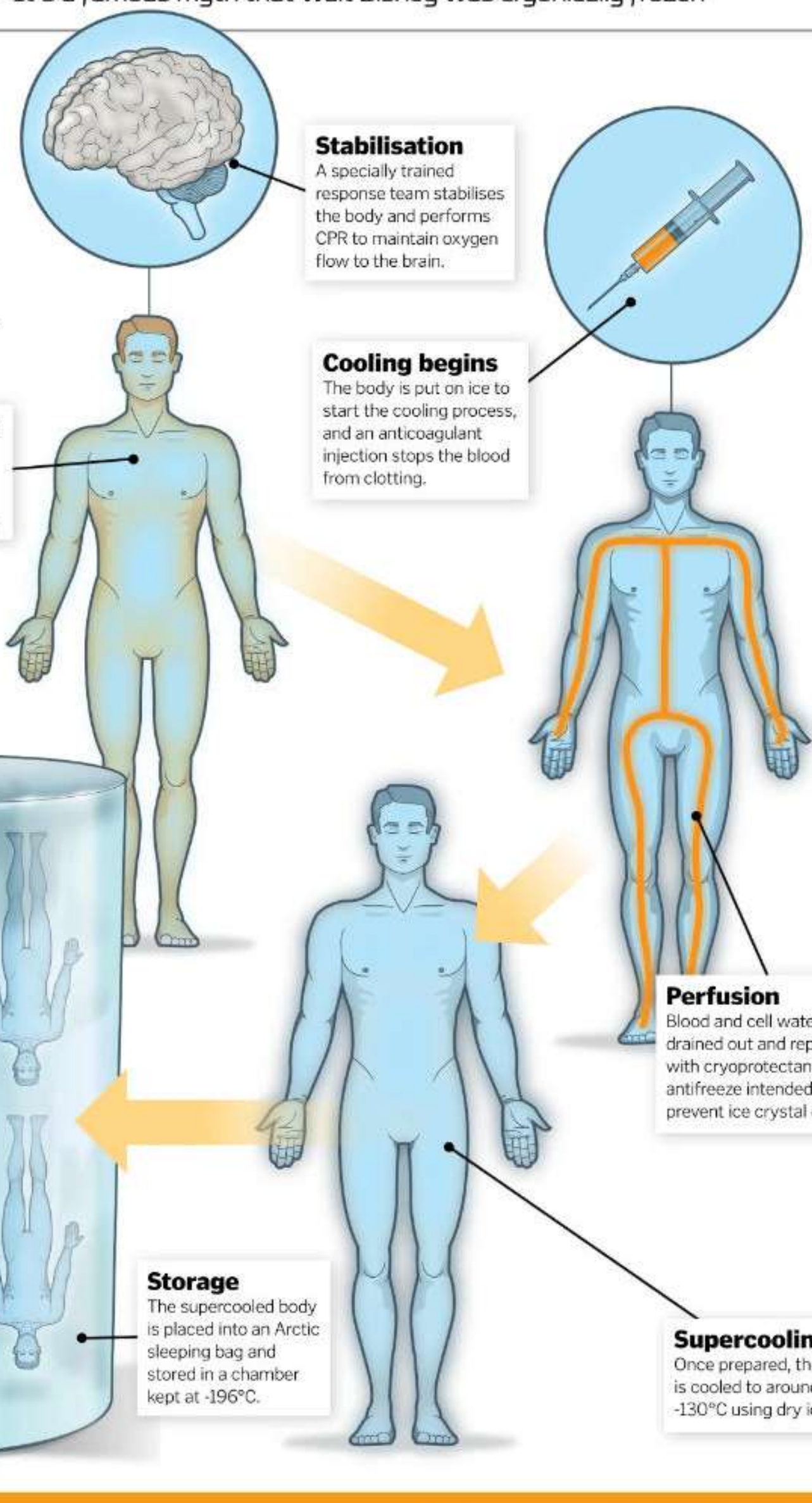
Sperm, egg cells and embryos can be frozen for later use in fertility treatment

Cryonics response teams practise on a dummy, training to prepare bodies as quickly as possible

© Getty

Cryonic cooling process

Preparation for storage needs to be fast and immediate



Stabilisation
A specially trained response team stabilises the body and performs CPR to maintain oxygen flow to the brain.

Cooling begins
The body is put on ice to start the cooling process, and an anticoagulant injection stops the blood from clotting.

Rapid response
The cryonic freezing process must begin as soon as a person is declared clinically dead.

Inverted
Bodies are stored upside down so that their brains remain preserved in liquid nitrogen if the tank leaks.

Perfusion
Blood and cell water are drained out and replaced with cryoprotectant, an antifreeze intended to prevent ice crystal damage.

Storage
The supercooled body is placed into an Arctic sleeping bag and stored in a chamber kept at -196°C.

Supercooling
Once prepared, the body is cooled to around -130°C using dry ice.

Back from the dead

Humans may currently be unable to recover from being frozen, but it's a normal part of life for other organisms. Wood frogs living in Alaska freeze when the unforgiving winter arrives – their hearts, blood and breathing stop entirely. Anyone coming across a solid wood frog would be forgiven for assuming it was dead, but come the spring the amphibian thaws and hops off to resume its usual business.

It turns out that Alaskan wood frogs produce a natural antifreeze. This cryoprotectant stops ice crystals from forming within the cells and damaging the body, allowing the frogs to shut down and hibernate for seven months each year.

When temperatures rise in spring, wood frogs thaw, rehydrate and carry on

All aboard HMS Enterprise

See inside this Royal Navy ship and discover how it surveys the seafloor

Words by **Scott Dutfield**

Berthed in London's financial district, HMS Enterprise (H88) seemed out of place between the skyscrapers of Canary Wharf. It's also an unusual ship for the Royal Navy, as this vessel is not built for battle but to scan the ocean bed.

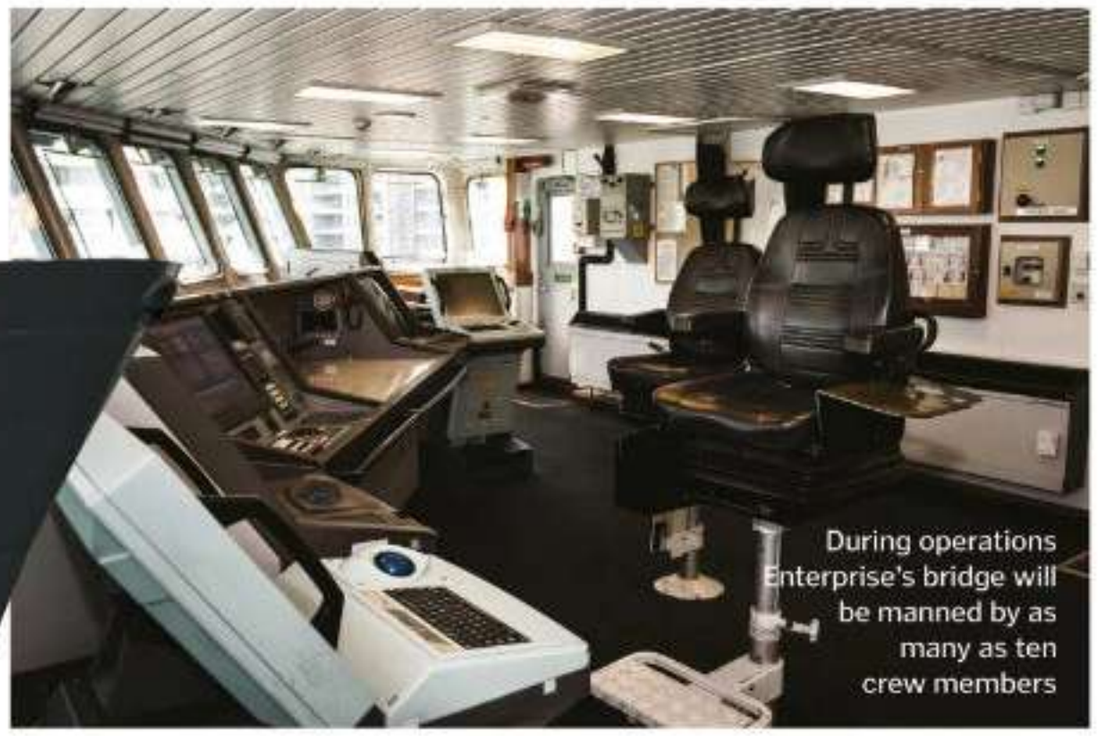
Our journey around the insides of Enterprise revealed it to be compact, as was the gangway to the deck of the ship. Filled with a network of narrow corridors, the bowels of the ship form a military maze, filled with the hustle and bustle of its 50 crew members. The ship's total workforce is a company of 80, split into three watches, each rotating every four to five weeks.

Everyone aboard Enterprise plays a key role in its maritime functions – from navigation, engineering and communications, to analysing the vital information gathered from the ship's sonar technology. The principal role of this ship is to gather data and information from below the waves. Using a multibeam echosounder, a type of sonar, officers and ratings aboard HMS Enterprise are able to construct highly accurate 3D models of the seafloor.

Similar to the way bats use echolocation, the sonar emits soundwave pulses, known as a ping, to a depth of around 1,000 metres. Once the soundwaves reach dense material below the sea, such as rock, the waves reverberate back towards the ship in the form of echoes. Once the echoes are received by the sonar, the time taken to receive the waves following transmission is calculated and the depth can be determined. As a multibeam sonar, hundreds of points are collected and recorded, as opposed to a single-beam sonar, which only determines the depth at a single point. As Enterprise moves through the waves the sonar continually sends and receives soundwaves, which can be used to generate a corridor model of the seafloor.

Receiving instructions from the UK Hydrographic Office, Enterprise and its crew will

Side-scan sonar is used to get up-close and personal with objects on the seafloor



During operations Enterprise's bridge will be manned by as many as ten crew members

undertake a variety of tasks while out at sea. Frequently it is the ship's mission to assess pathways along the sea for other ships seeking safe passage. The maps generated from the multibeam sonar allow other ships to avoid any geological structures that might impede their journey. Across the Pacific Ocean, survey ships also play a vital role in understanding the depth and breadth of submarine volcanic activity. In known locations of a new or recent eruption, ships such as Enterprise are able to monitor the activity to assist the movement other navy vessels, such as submarines.

To get an even better picture of what lies on the seabed, additional sensory equipment called side-scan sonars are cast overboard and towed as the ship moves. Operating in a similar way to the ship's multibeam sonar, side-scan sonars are lowered hundreds of metres into the water, where the echoes of emitted sound are recorded. This close-contact sonar gives navy personnel the chance to gain a clearer image of what's below them. These torpedo-shaped sonars are also an excellent method of locating historical shipwrecks and, more importantly for the safety of shipping, any unexploded ordnance or mines that may be lurking deep below.

www.howitworksdaily.com

Testing the waters

One of the accessories that HMS Enterprise and some other survey ships have at their disposal is an Undulating Oceanographic Recorder (UOR). This aircraft-shaped sensor is able to reveal more information about the ocean water itself. From monitoring water salinity, temperature and plankton concentration, these sensors can provide a vital insight for submarine missions. Generating its power through its rear propellers, the UOR uses its moveable fins to ascend and descend through the water. It's towed by an extended cable, allowing the UOR to descend to around 200 metres, depending on the ship's speed.

These undulating recorders are able to decipher information about the surrounding water

SURVEY SQUAD

The Royal Navy has a fleet of hydrographic survey ships designed to scan the seas

HMS SCOTT (H131)

As the largest of the hydrographic fleet and of any survey ship in western Europe, this 13,500-ton behemoth is named after the famous Arctic explorer Robert Falcon Scott.

HMS ECHO (H87)

Similar in size and shape to Enterprise, this 5,000-ton ship bears the name of the Royal Navy's first ever survey vessel, in service in 1827.

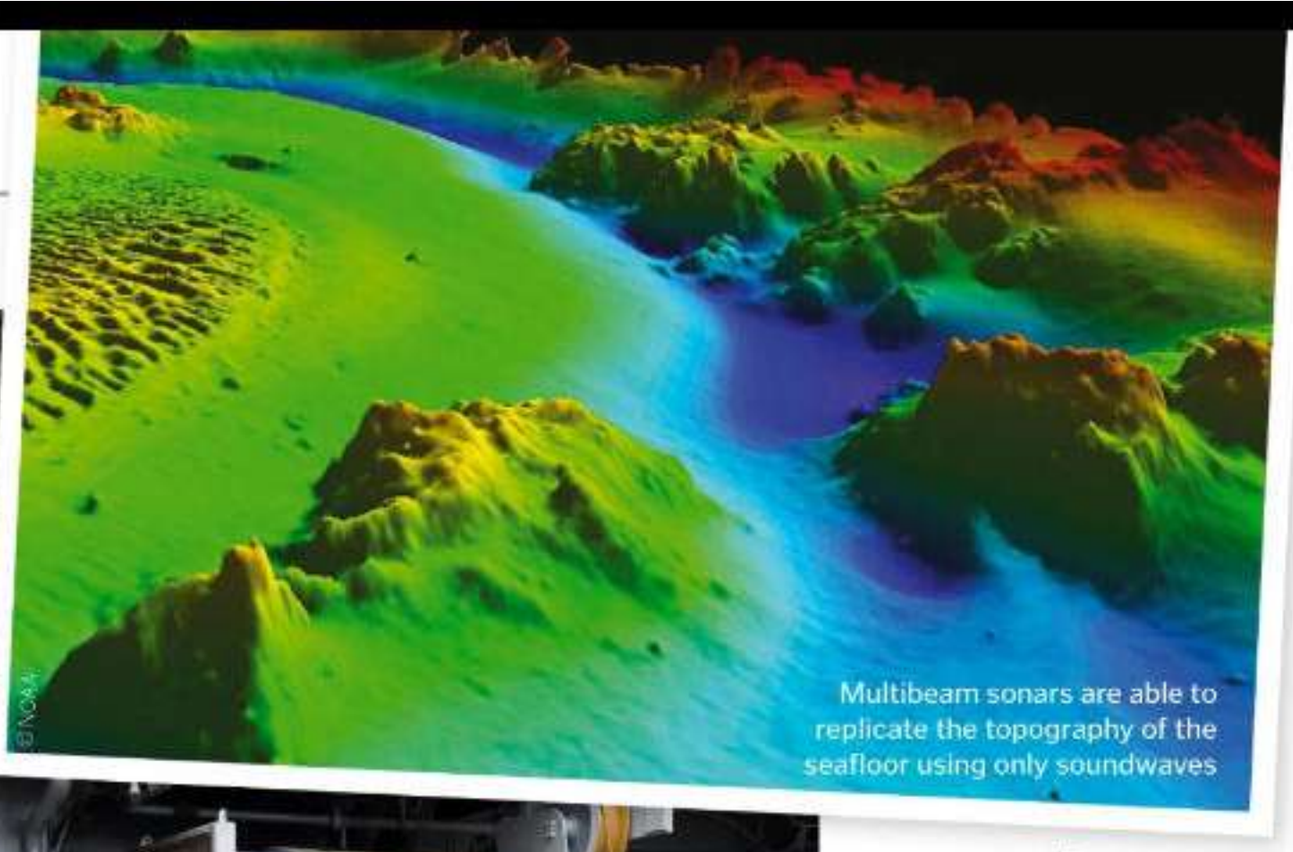
HMS PROTECTOR (A173)

Spending the majority of its time sailing through the waters of Antarctica, this survey vessel is equipped with a hull that can glide through ice up to half a metre thick.

HMS MAGPIE (H130)

The newest and smallest member of the Royal Navy's hydrographic squadron, Magpie weighs in at only 37 tons, but its small size allows it to survey areas unreachable by other ships.

Though it's not designed primarily to engage in conflict, Enterprise is still equipped with two large 20mm cannons



Multibeam sonars are able to replicate the topography of the seafloor using only soundwaves

Side-scan sonars are released into the water via a large winch

Between decks

What makes HMS Enterprise such a good survey vessel?

Sonar winch
Much like casting a fishing net, side-scan sonars are released into the water at the end of a line and reeled back in once the survey is concluded.

Deck crane
HMS Enterprise uses a deck crane to launch a mini survey unit – a motorboat called Spitfire – to access remote areas.

Survey room
Data collected from the multibeam sonar and side-scan sonars is analysed in the survey room, and maps are produced for future use.

Azimuth thrusters
High-power propeller engines move the heavy load of Enterprise, which has travelled over 80,000 kilometres since its launch.

Enterprise through the ages

1705
The first Enterprise ship (L'Entreprise) was captured from the French in the early 1700s by the 50-gun HMS Triton.

1709
Having lost the first edition in 1707, the second-edition Enterprise was a two-decked, 44-gun ship.

1741
The intended third edition never actually bore the name Enterprise. It was renamed HMS Liverpool at the last minute. The fourth Enterprise set sail three years later.

1775
Captured by American forces, the fifth Enterprise was quickly replaced with the sixth edition, which served as a convoy escort.

Scanning the seafloor

Another addition to the technical crew aboard HMS Enterprise is the GeoChip, a sub bottom profiler used to analyse the seabed's geology. Able to penetrate the first couple of metres of the seafloor, this large sonar emits short pulses through the floor and records the strength of the returning signal. If it hits dense bedrock the returning signal will be stronger than if it hits layers of lightly packed silt, for example. The data collected will then provide a virtual cutaway of the rock below, revealing the varying layers of sediment.

Checking the geology of the seafloor, GeoChips are able to use sound to penetrate rock layers

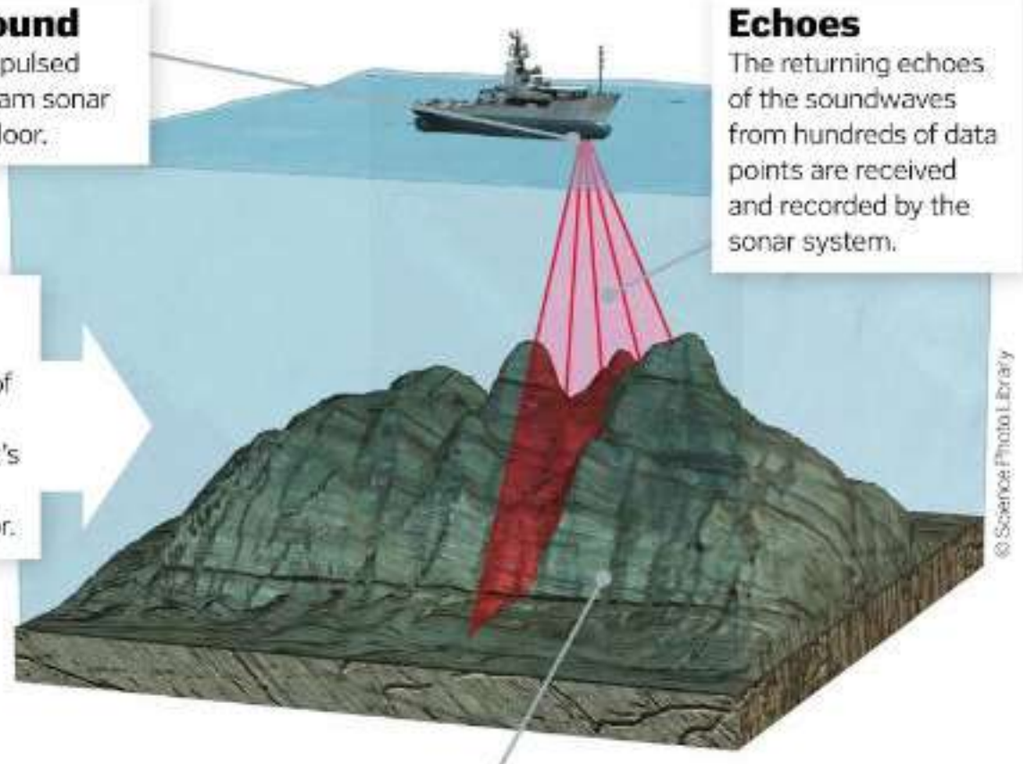
Communications
Radar and satellite GPS enable Enterprise to pinpoint its exact location, which is vital for creating maps of the ocean floor.

Bridge
The bridge is where the brains behind the operation reside. Here, the captain and the navigation personnel monitor and control the ship's activities.

Emitting sound
Soundwaves are pulsed from the multibeam sonar towards the seafloor.

Echoes
The returning echoes of the soundwaves from hundreds of data points are received and recorded by the sonar system.

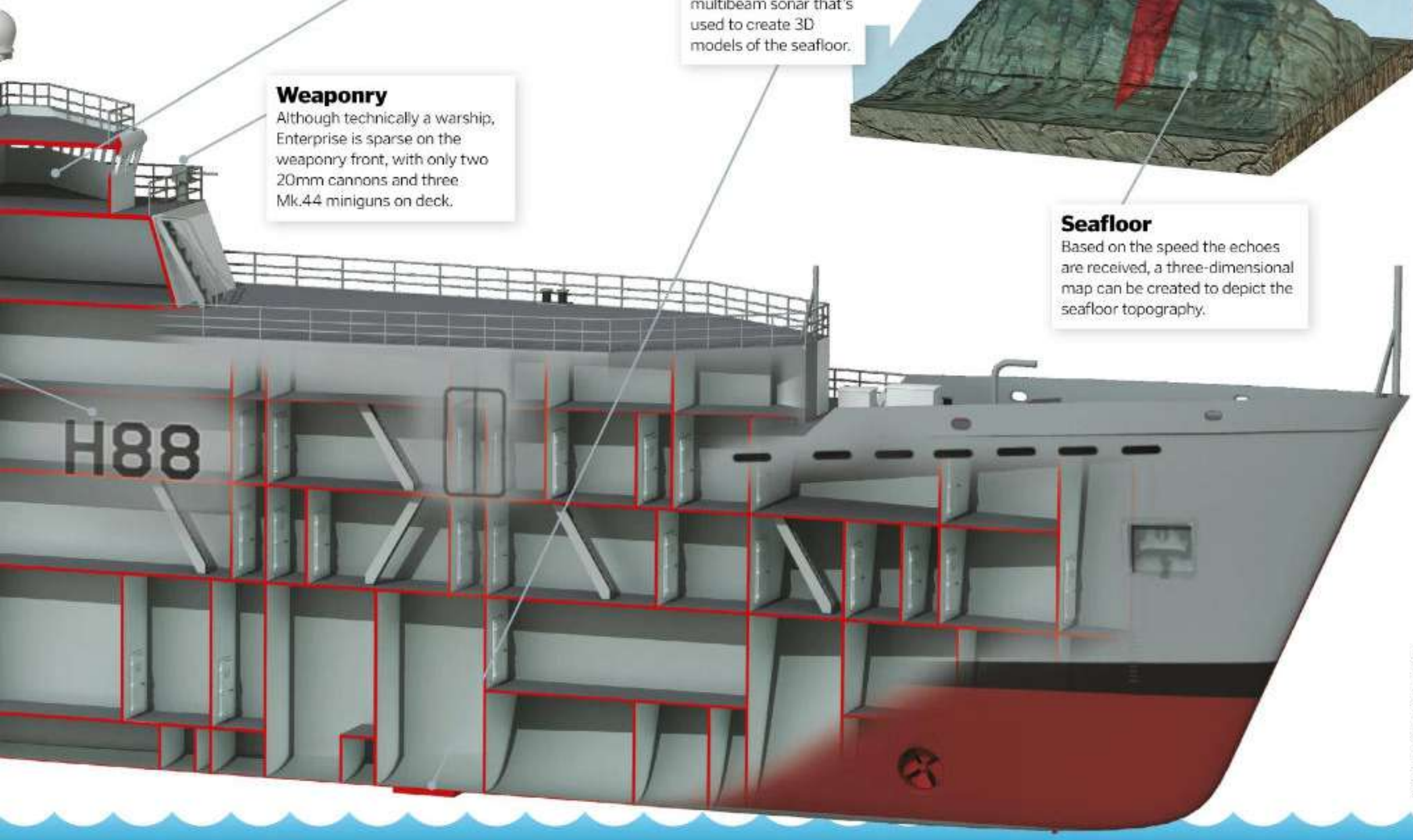
Multibeam echosounder
Mounted to the keel of Enterprise is a multibeam sonar that's used to create 3D models of the seafloor.



© Science Photo Library

Weaponry
Although technically a warship, Enterprise is sparse on the weaponry front, with only two 20mm cannons and three Mk.44 miniguns on deck.

Seafloor
Based on the speed the echoes are received, a three-dimensional map can be created to depict the seafloor topography.



© Illustration by Aaron Mann

1778
After its launch, Enterprise was soon converted to carry heavy weapons and act as a floating battery in 1804.

1848
The ninth edition of Enterprise was launched and helped in the search for Sir John Franklin's lost Arctic expedition.

1926
Serving until 1937, the 12th edition of Enterprise was then recommissioned due to the outbreak of World War II.

1958
The penultimate version of Enterprise, which was known as Starship, surveyed the English Channel and coastlines.

2003
The modern-day HMS Enterprise was launched as a Royal Navy hydrographic survey vessel in 2003.

How electric aeroplanes work

Inside the aircraft that's leaving smaller carbon footprints in the sky than hi-octane jets

Right now, there are an estimated 20,000 aeroplanes in use around the world. Around 3 billion people travel on these planes, which account for four per cent of all greenhouse gas emissions. By 2040 it is thought that there are going to be more than double this number in use.

To control the impact this could have on the Earth's climate, electric aircraft are providing a more sustainable solution to air travel. Electric engines have been designed in an attempt to create an emission-free air industry. In today's connected world, there is a growing demand for air travel, so work needs to be done quickly to counteract the potential damage this demand could have on the planet.

Electricity can be used to power electric aircraft in a variety of ways, including batteries, ground power cables, solar cells and power beaming. Power beaming involves the wireless delivery of energy to the aircraft from a remote power plant: the most common methods of this are through microwaves or lasers.

Electric travel was previously regarded as a dream for the future, until encouraging progress began to be made. In 2016, Solar Impulse 2 brought the electric dream further into reality. The electricity-powered aircraft was the first of its kind to complete a trip around the globe, in a journey that took a full 16 months. During this time no fuel was burned: it was a zero-emission trip.

Solar Impulse 2's pilots celebrate their journey

© Getty

5 FACTS ABOUT ELECTRIC AEROPLANES

1 Flying locally
There is a big demand for small electric planes: 2 billion tickets are sold each year for flights shorter than 800 kilometres.

2 Centuries of progress
Although the use of electric-powered aircraft is on the rise, the invention is not new. This type of flight was first tested in the 1800s.

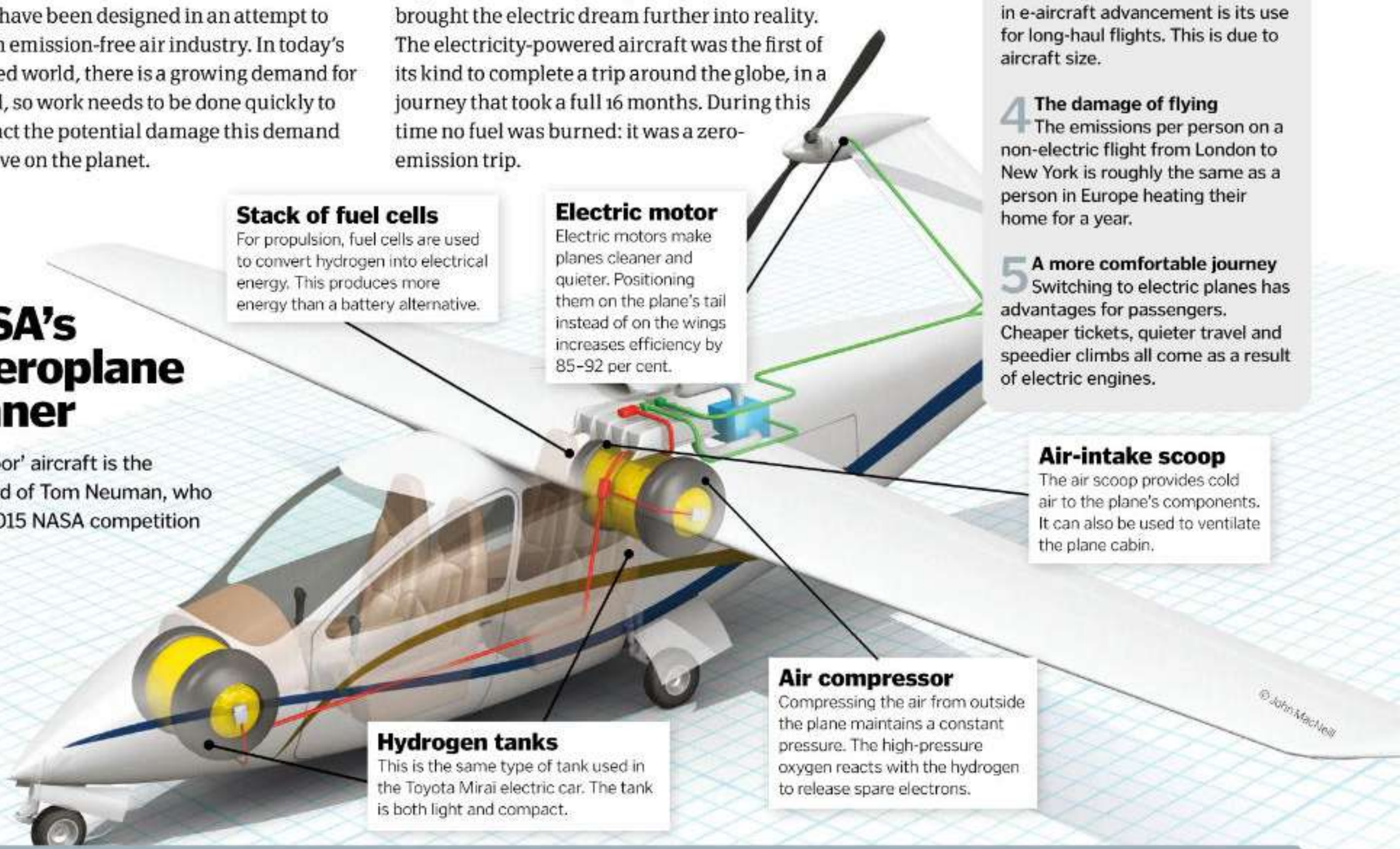
3 Limited distance
It may be a long wait before you can fly from the UK to Australia, electrically. The current drawback in e-aircraft advancement is its use for long-haul flights. This is due to aircraft size.

4 The damage of flying
The emissions per person on a non-electric flight from London to New York is roughly the same as a person in Europe heating their home for a year.

5 A more comfortable journey
Switching to electric planes has advantages for passengers. Cheaper tickets, quieter travel and speedier climbs all come as a result of electric engines.

NASA's e-aeroplane winner

The 'Vapor' aircraft is the brainchild of Tom Neuman, who won a 2015 NASA competition



Stack of fuel cells
For propulsion, fuel cells are used to convert hydrogen into electrical energy. This produces more energy than a battery alternative.

Electric motor
Electric motors make planes cleaner and quieter. Positioning them on the plane's tail instead of on the wings increases efficiency by 85–92 per cent.

Air-intake scoop
The air scoop provides cold air to the plane's components. It can also be used to ventilate the plane cabin.

Air compressor
Compressing the air from outside the plane maintains a constant pressure. The high-pressure oxygen reacts with the hydrogen to release spare electrons.

Hydrogen tanks
This is the same type of tank used in the Toyota Mirai electric car. The tank is both light and compact.

© John MacNeill

Building effective electric aircraft

Electric flights are still being tested, with 2022 set as the year when customers can take fully electric flights. Becoming electric brings visual changes. The large engines found under the wings of standard planes will no longer be necessary. Instead, many designs show an electric propulsion system distributed along the wing. The wings may also be longer and thinner, to improve efficiency and reduce drag. Weight also needs to be monitored: adding an extra kilogram would require every part of a plane's structure to be made bigger. Per unit of weight, an electric aircraft's battery stores 40 times less energy than jet fuel. But a higher percentage of the energy can be used to drive the aircraft. So, while less energy is created in an electric plane per kilogram, this energy will be used to cover a larger distance.

Prototype electric plane 'Alice' is set to be the world's first commercial electric aircraft in 2022

© BBC News

© Mr. Bean

and BRILLIANT*

The beloved ~~oddball~~ Mr Bean famously drives a 1976 British Leyland Mini 1000 on his adventures. The 'Citron' lime green coloured car is fitted with numerous ~~bizarre~~ GENIUS security features including a bolted latch and padlock on the driver's door and a removable steering wheel.

← Not on this tiny model!

* NB: This product description has been skilfully corrected by Mr Bean (of London)

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Inside e-bikes

How electricity is powering a new wave of enthusiasm for cycling

If someone cycles past you up a steep hill looking serene and sweat-free, they're either extremely fit or riding an electric bike. Electric bikes still have pedals and can be ridden like conventional bicycles, but integrated motors add power and propulsion when needed. They range from bikes with small motors that assist when a cyclist is pedalling (known as pedelecs) to models with throttles, which are able to operate like mopeds when the rider engages the motor.

While electric bikes – or e-bikes – have enjoyed a real surge in popularity since the late 1990s, they've been around since the Victorian era. Ambitious inventors and engineers first attached motors to bicycles in the 1880s. Electric bikes had the potential to ease traffic and pollution, but heavy, electrically driven wheels and weak batteries made early attempts impractical.

The invention of the lithium-ion battery in 1991 finally made lightweight electric bikes a reality. An e-bike can now cover more than 100 kilometres before it needs charging.

E-bikes don't do all the work for cyclists, but they do make cycling considerably easier and more accessible. From city commutes to countryside adventures, electric bikes reduce the amount of effort cyclists need to put into their journeys while providing that wind-in-your-hair feeling.

Tens of millions electric bicycles are now ridden every day in China. In the Netherlands adults are buying more electric bikes than non-electric models, and it's predicted that it won't be long before one in three bikes sold across central Europe will be electric. As well as providing financial benefits for the countries manufacturing and distributing the bikes, it's hoped that this boom in sales will improve health as more people choose to cycle.

"Ambitious inventors and engineers first attached motors to bicycles in the 1880s"

The motor on an electric bike adds power to a cyclist's pedalling

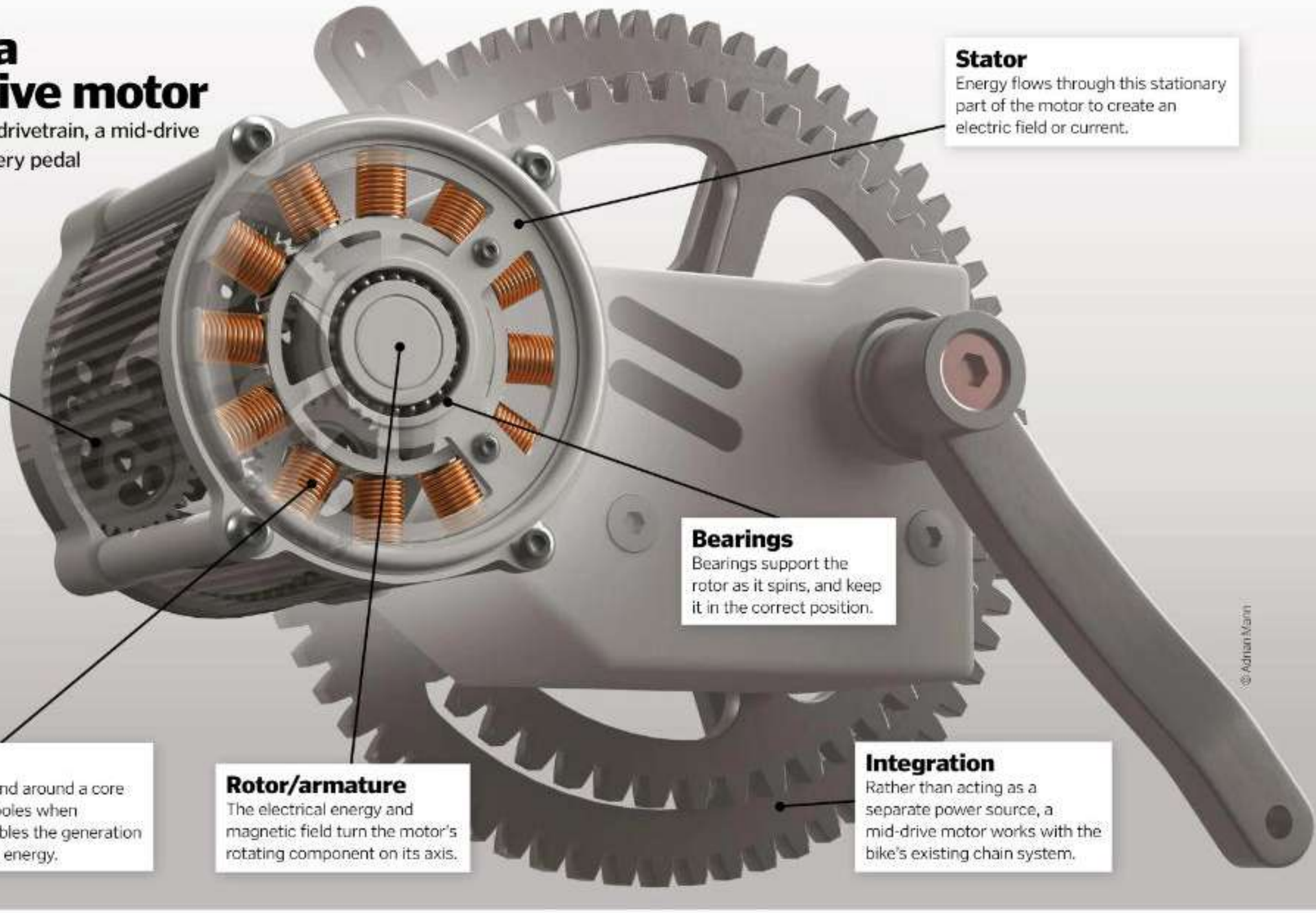
Safety first

Electric bikes can make cycling easier and quicker, but they're just as likely to be involved in an incident if not used carefully. Because of their increased weight and speed, it's important to pay careful attention to the road, so you can brake or steer in plenty of time to avoid hazards. Drivers will often base their decisions on the speed of a normal bike, so always stay alert in case a car pulls out in front of you. Cyclists riding electric bikes should also take the usual safety precautions, like using lights and reflective clothing at night and wearing a helmet.

Higher speeds make head protection like this Hedkayse ONE helmet essential while riding an electric bike

Inside a mid-drive motor

Using the bike's drivetrain, a mid-drive motor makes every pedal more powerful



Shaft
Turned by the movement of the rotor, the shaft delivers mechanical energy and torque to the bike's drivetrain.

Stator
Energy flows through this stationary part of the motor to create an electric field or current.

Bearings
Bearings support the rotor as it spins, and keep it in the correct position.

Windings
Insulated wire wound around a core creates magnetic poles when energised, and enables the generation of electromagnetic energy.

Rotor/armature
The electrical energy and magnetic field turn the motor's rotating component on its axis.

Integration
Rather than acting as a separate power source, a mid-drive motor works with the bike's existing chain system.

Pedal Power

Battery
Batteries take two to eight hours to charge fully, and act as the power source for the bike's motor.

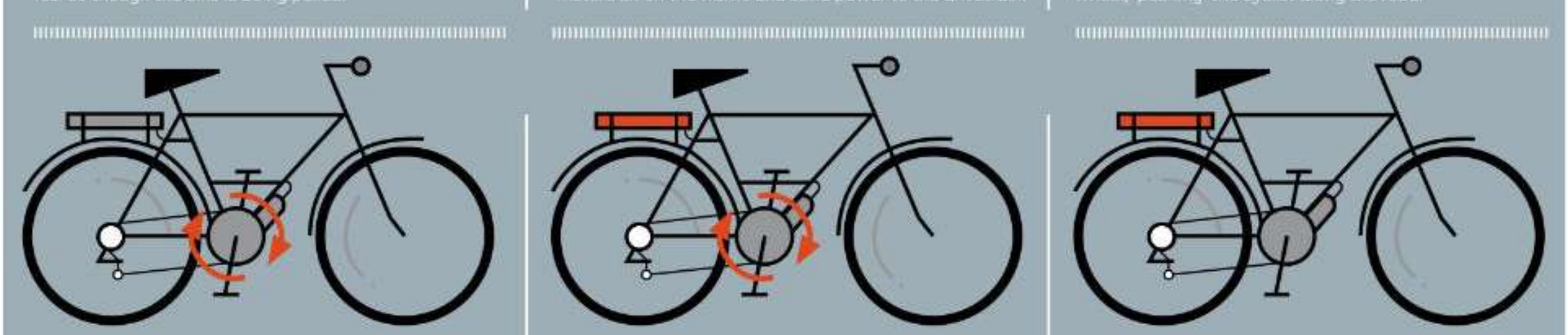
Drivetrain
The drivetrain is a collection of components that deliver power from the motor to a bike's wheel.

Motor
The motor converts the battery's electrical energy into mechanical energy to propel the bicycle.

Front hub motor
A front hub motor spins the bike's front wheel, making it feel as though the bike is being pulled.

Mid-drive motor
For a more conventional cycling experience, mid-drive motors sit on the frame and send power to the drivetrain.

Rear hub motor
Rear hub motors provide power to a bike's back wheel, 'pushing' the cyclist along the road.



Pedal only
A conventional bike gets all its power and movement from the cyclist's effort on the pedals.

Pedal assist
The motor on a pedal-assist bike is activated only when a cyclist is pedalling, providing them with extra propulsion.

Power on demand
The throttle on a power-on-demand bicycle gives the rider a boost whenever they want it, pedalling or not.

How planes use smart radar

The radio waves that keep you safe in the sky and on land

What's the weather going to be this afternoon? Tomorrow? Or even next week? Thanks to the weather forecast, we are able to plan ahead when it comes to the weather. Long gone are the days when you could only rely on a glance out of the window in search of a dry day.

Weather forecasts often show predictions for large areas of the country, but smart weather radars make it possible to receive precise climate conditions for the exact location where they are placed. You can even buy weather stations designed for your home that send automatic message notifications when extreme conditions are expected.

Hyperlocal results provide higher accuracy in a weather radar's feedback. This becomes useful for closely following updates, especially when they could cause danger. Examples of when this technology is required includes on transport that's affected by weather, as well as in agriculture, to show flood warnings.

But how is the information collected? Radar stands for radio detection and ranging, which is used by weather stations and aeroplanes to send radio waves out into the sky. The waves bounce off the nearest object - like a cloud - they come into contact with and return to be analysed.

Data from these radars can determine details about precipitation in an area, such as its location, how much precipitation is in the air, its movement and the likelihood of future snow, hail or rainfall.

Additionally, the radar system can predict the possible effects of incoming storms. While we often seek weather forecasts for convenience, this information holds the more important purpose of ensuring safety.

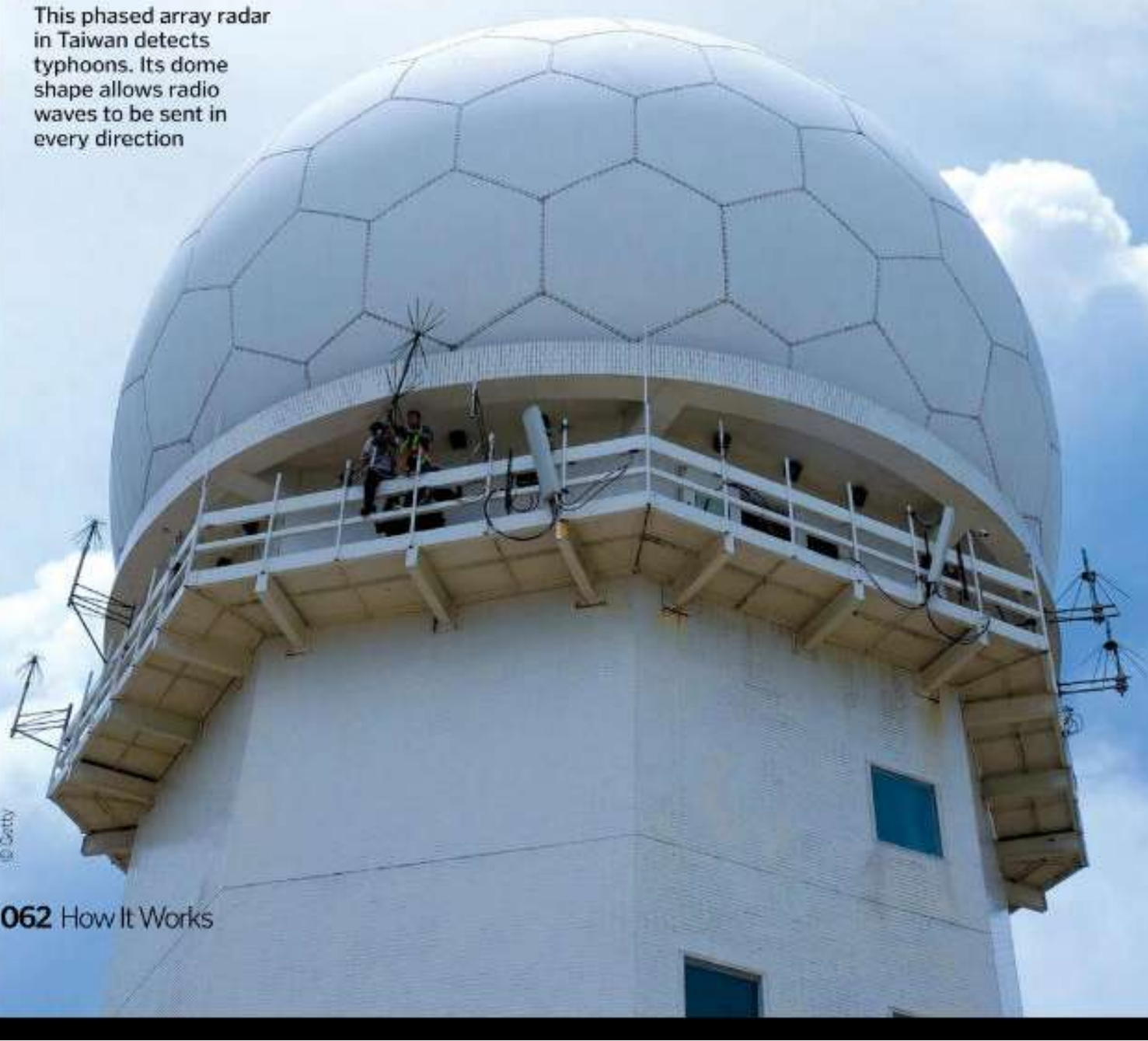
The speediest surveillance

Phased array radars (PARs) can be used to detect weather conditions electronically, using an array of antennae. The beams from these radars can be steered quickly for fast and accurate weather forecasts.

High-speed tracking means that these radars not only save time but occasionally lives too. They have been used to warn people about severe weather in advance, such as in the US where they have been able to prepare for incoming tornadoes.

PARs contain panels that face in every direction. Unlike many weather stations, which need to rotate to cover the surrounding areas, PARs remain stationary, scanning the entire sky in under 60 seconds. Tracking both air and ground level at the same time, these qualities also provide a perfect use for navigating warships in many navies, as well as controlling missiles.

This phased array radar in Taiwan detects typhoons. Its dome shape allows radio waves to be sent in every direction



© Getty

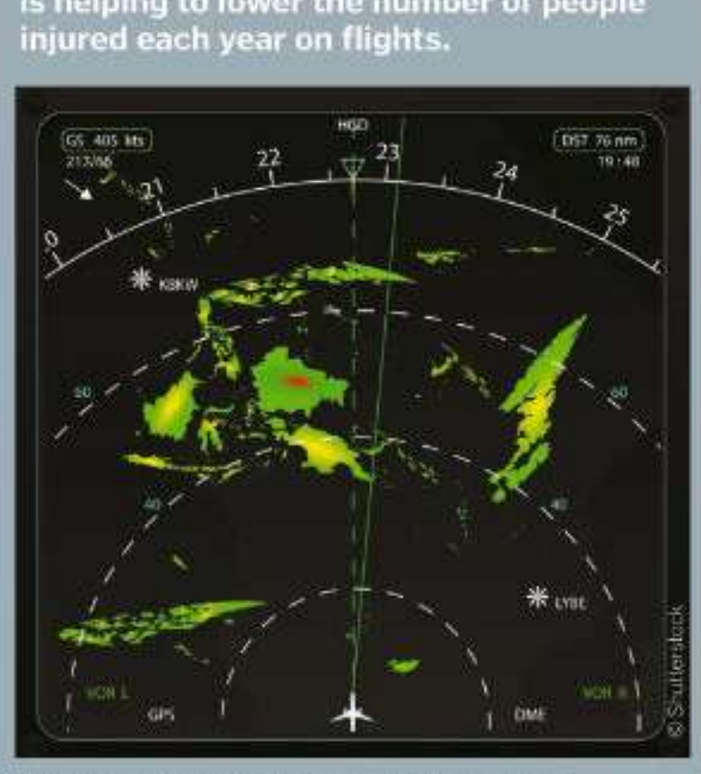
Reducing injuries in the sky

If you're a frequent flyer, you will be no stranger to the rollercoaster-style drops and involuntary shakes you can suddenly experience mid-flight.

As conditions can vary immensely across the sky and over different landscapes, most large planes are equipped with smart weather radar systems. This helps to predict the likelihood of turbulence.

When radio waves return to the radar, they vary in strength, with stronger reflections indicating a higher concentration of water droplets. This outcome is translated into colours on a screen in the cockpit – red showing high density, orange showing medium and green illustrating low density.

Stormy areas often lead to turbulence, so receiving a clear picture of storms that lie ahead makes it easier to determine when it may strike. Warning passengers in advance optimises their safety, and it is helping to lower the number of people injured each year on flights.



Weather radars on planes provide constant feedback, keeping images up to date

Pilots can adjust radars to cover all areas. Mountainous landscapes below regularly cause turbulence, as warm air is forced upwards

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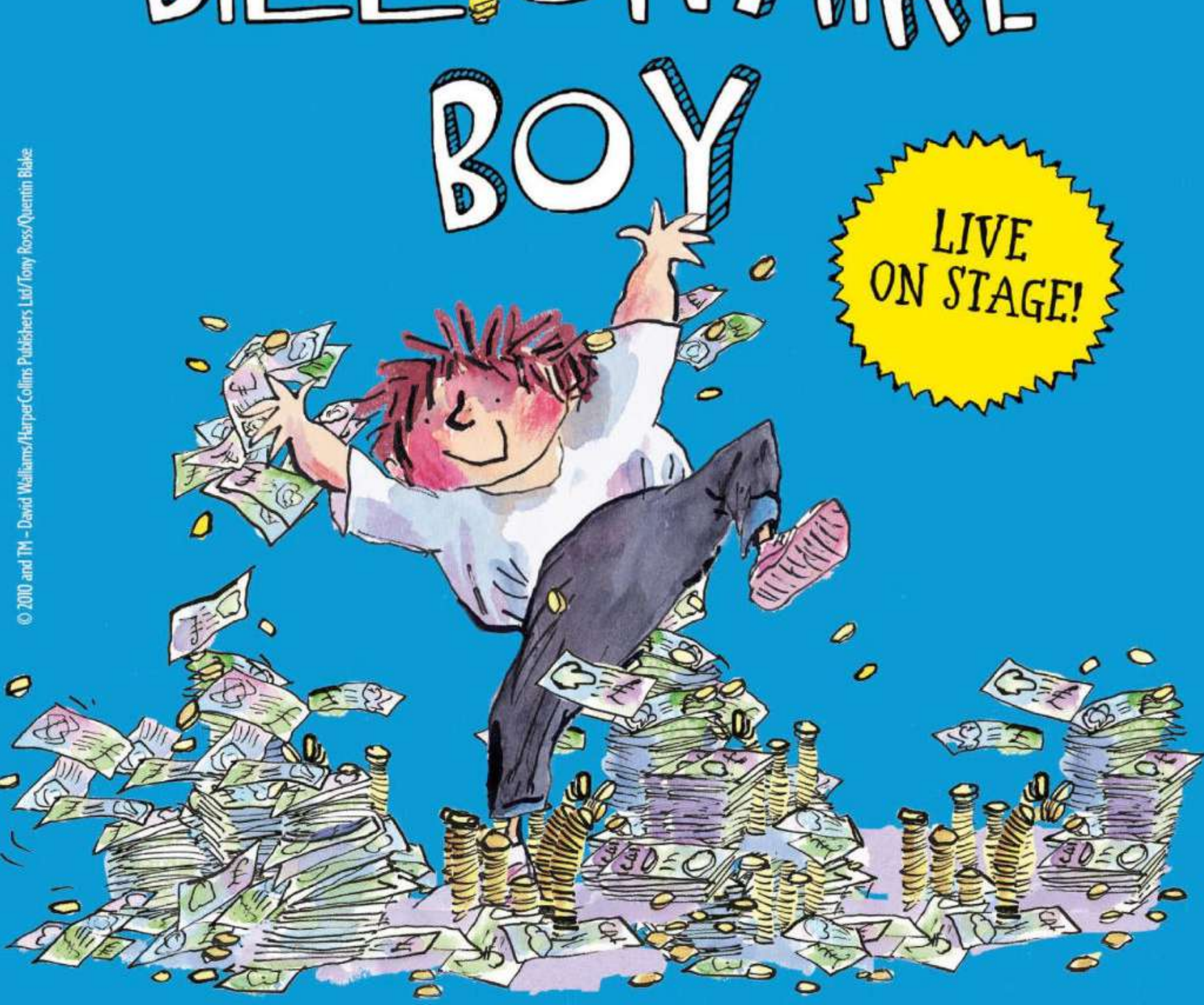

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WHAT IS PERMAFROST?

This permanently frozen ground in Arctic regions has major consequences for global warming

Words by **Amy Grisdale**

Almost 15 million square kilometres of Earth's ground is frozen solid. Permafrost covers nearly as much of the planet as Russia does. Soil, silt or clay must stay at zero degrees Celsius or lower for two years to qualify as permafrost, and it's over one kilometre thick in parts of Siberia. Some areas of permafrost are so laden with ice that it's twice the weight of the soil around it. In Alaska subterranean blocks of ice reach 35 metres deep and span 500 kilometres.

These vast frozen areas are remnants of the last ice age. They formed over thousands of years and have survived until the present day. Each summer the top layer of the frozen soil could thaw enough for plants to grow. As time went on, a lot of organic matter found its way into the soil. Eventually vegetation and animal

DID YOU KNOW? *Some permafrost bacteria live 400 metres deep at temperatures of -27 degrees Celsius*

Previously frozen ground implodes when it isn't held together by ice any more

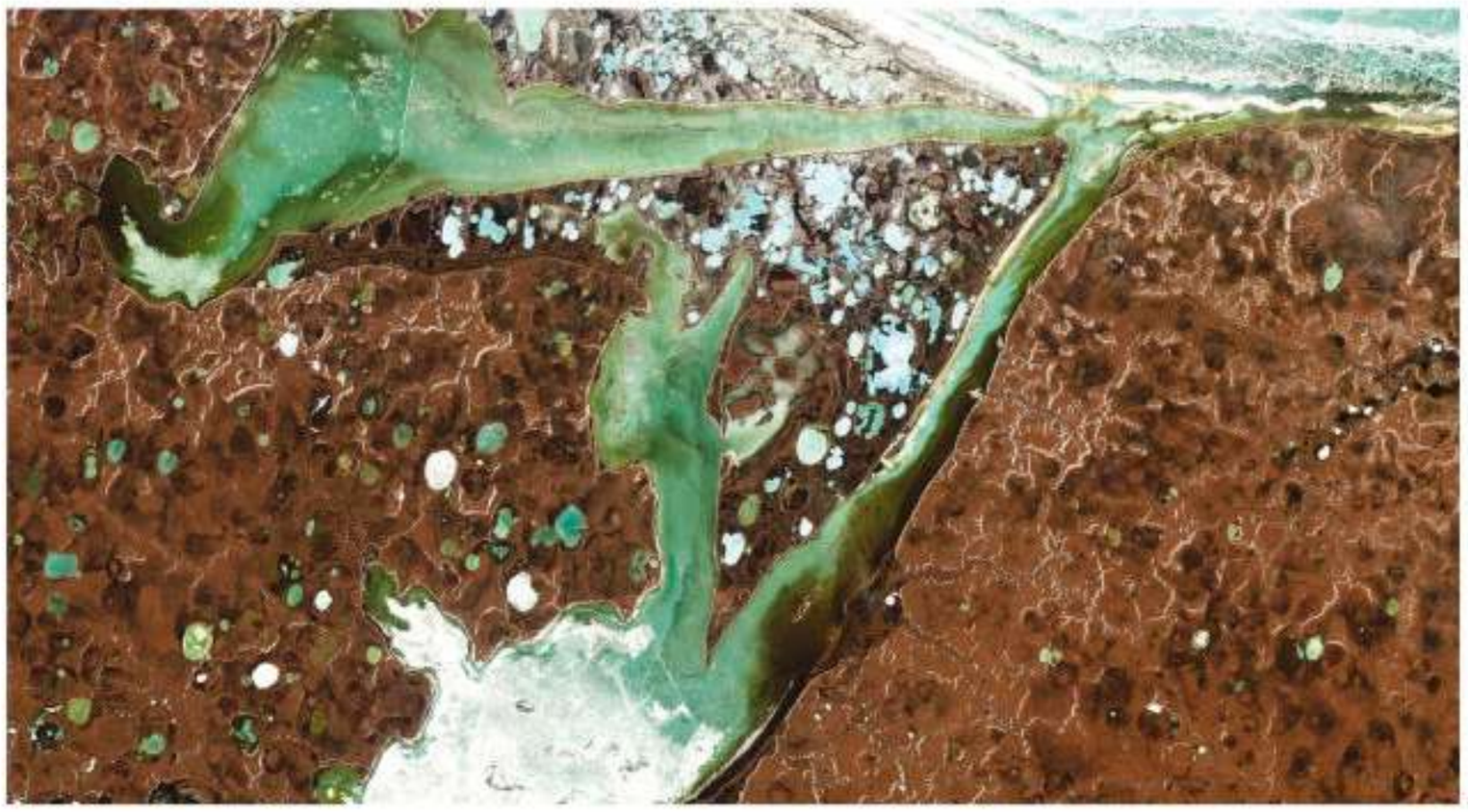
Prehistoric ivory

Because permafrost is so good at preserving animal tissue, there are thousands of mammoth tusks trapped underground. People visit Siberia to unearth these tusks – 90 per cent of which end up in China. Carved ivory ornaments are a status symbol, but elephant ivory is illegal in China. Mammoth ivory is considered an ethical source of ivory so the demand for it is sky high. A 65-kilogram tusk fetches £23,000.

But not only is the scientific community losing potential discoveries to the ivory trade; the permafrost itself is suffering. Mammoth hunters blast the ice with water and excavate cavernous tunnels, causing unnecessary damage. Sludge from the melted ground also runs into nearby rivers, making the water dirty and more dangerous to navigate.

The number of tusks still encased in permafrost seems to have diminished significantly, and hunters are struggling to find valuable prehistoric tusks now that they are in low supply.

Polar bears are at great risk from tusk hunters and are usually shot on sight to avoid conflict



© NASA

A satellite image of the north Siberia coast, showing thermokarst lakes, which are pockets of permafrost meltwater

remains were buried in the permafrost, where they couldn't decay. Intact remains of extinct megafauna are found in permafrost to this day in near-pristine condition.

All of this tissue would rot if global temperatures got high enough to melt the permafrost that's keeping it preserved. The bacteria that feed on decomposing material release greenhouse gases. If the planet gets hot enough, melting permafrost could accelerate climate change.

Permafrost prevents the ground from absorbing water, creating wetlands and lakes that normal rainfall couldn't sustain. People and wildlife rely on these environments to survive, and the loss of permafrost would have an enormous impact. If subterranean ice were to melt, the land would change drastically. Some areas would dry out, while others would get wetter. The chemical makeup of the water would change and the ground would become irregular. The new landscape could alter the course of rivers, affecting fish and wildlife.

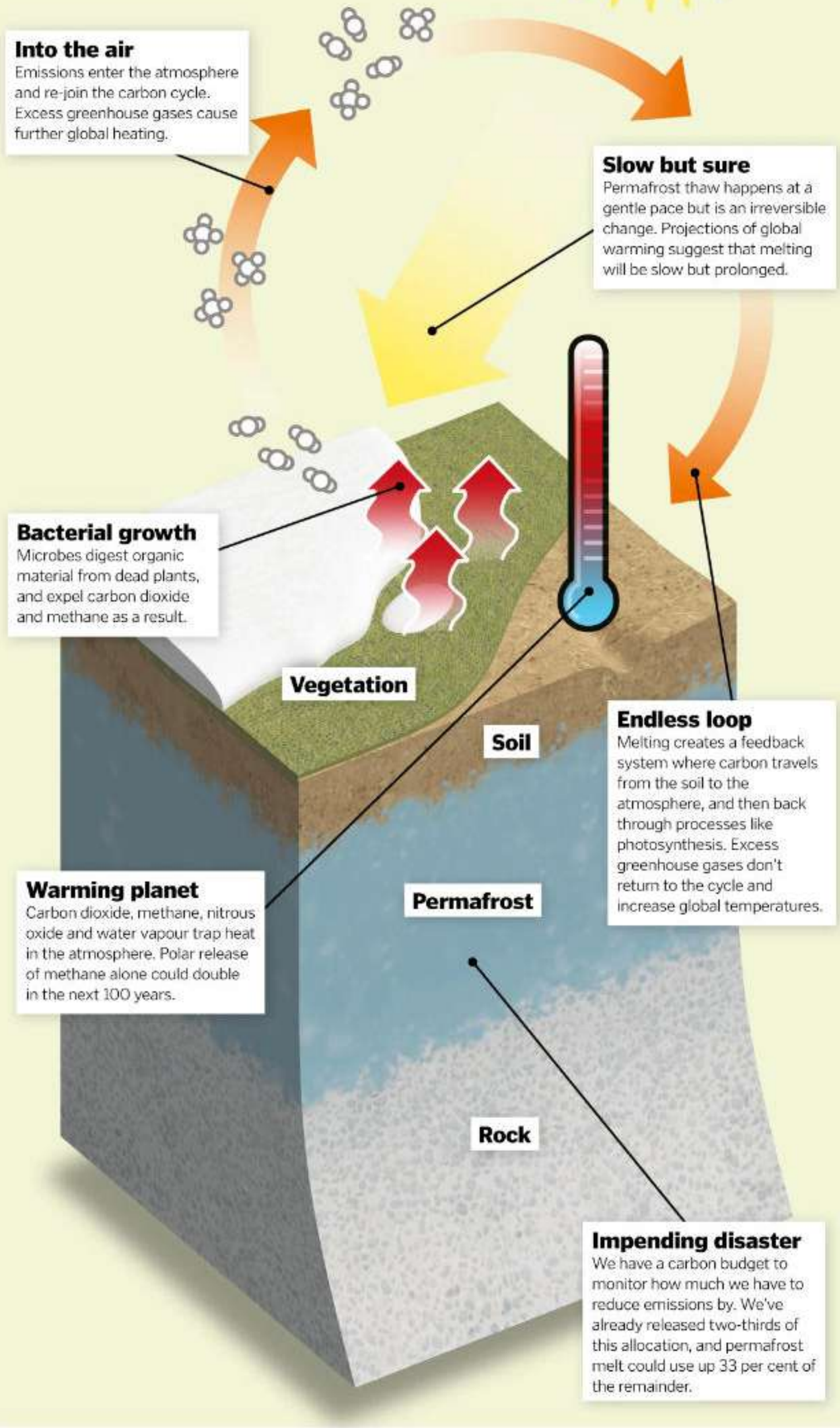
Unfortunately permafrost is beginning to melt thanks to our changing climate. While the local

"Polar release of methane alone could double in the next 100 years"

About 60 per cent of Russian land contains permafrost, and the country's scientists study it closely, measuring how it changes

How melting ice releases carbon

The planet's natural carbon cycle is under threat from the warming polar regions



© Adrian Mann

Crumbling tundra

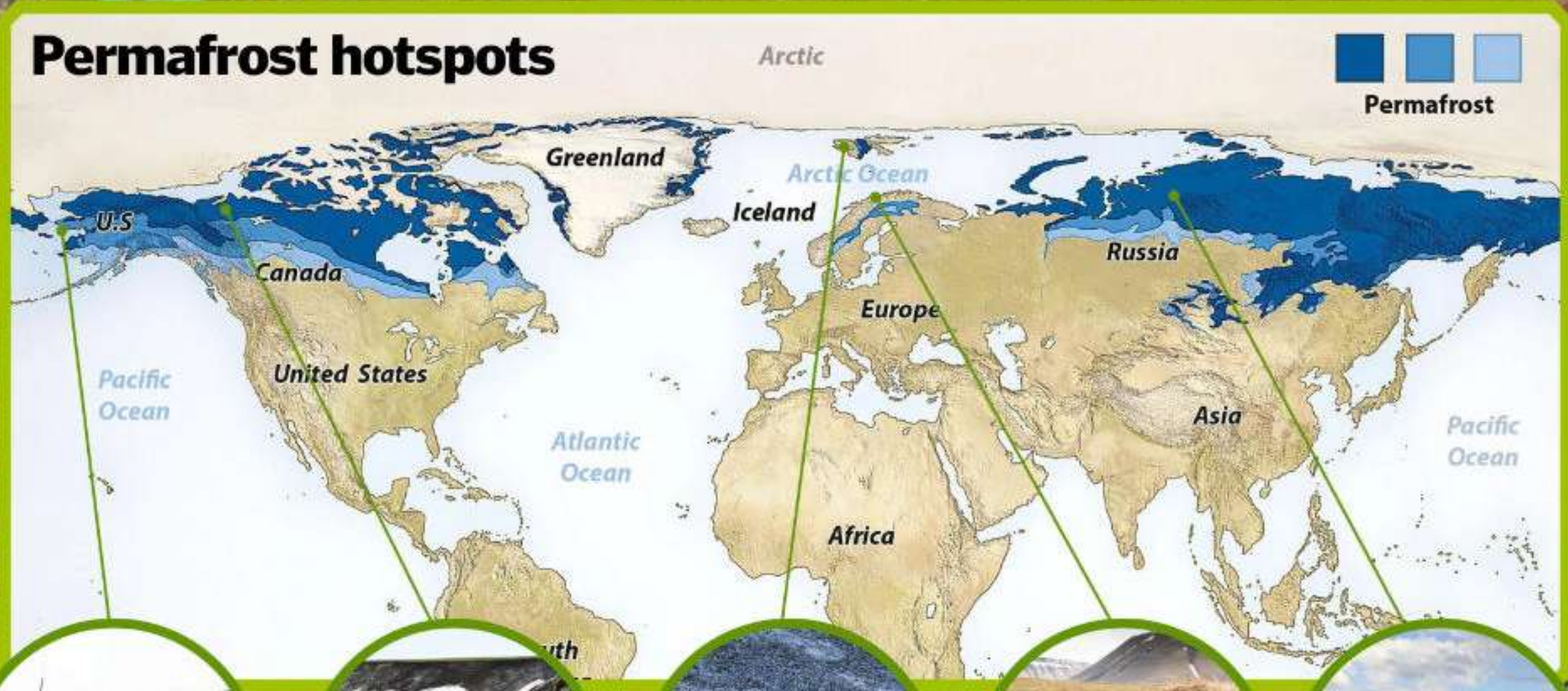
Surplus melted water creates fragile soil peppered with marshy potholes. In some cases huge divots appear, like the Batagaika crater in northeast Siberia. It's the biggest of its kind, stretching for more than a kilometre. It's still growing too. The cavity has been known to advance by 30 metres in years with warm weather. The giant hole first appeared after a stint of logging in the 1960s. The once-frozen ground was heated by exposure to direct sunlight and eventually caved in. Over the years it has been carved deeper by flooding, and more land collapse could be ahead as the crater advances towards a nearby valley. On the positive side, the opening of this cavernous pit has given scientists a new insight into the past. It has revealed 200,000 years of history of a planet that has undergone extreme temperature fluctuations for billions of years. Learning about climate change in this recent past could give us a better understanding of what the Earth is experiencing today.


The Batagaika crater started forming after logging activity exposed the frozen ground to direct sunlight

The crater grows every year, getting increasingly wide and deep


The crater is revealing thousands of years of history that's been buried and frozen underground

Permafrost hotspots



This Alaskan home was destroyed by climate change-fuelled erosion. The entire island may eventually be evacuated.

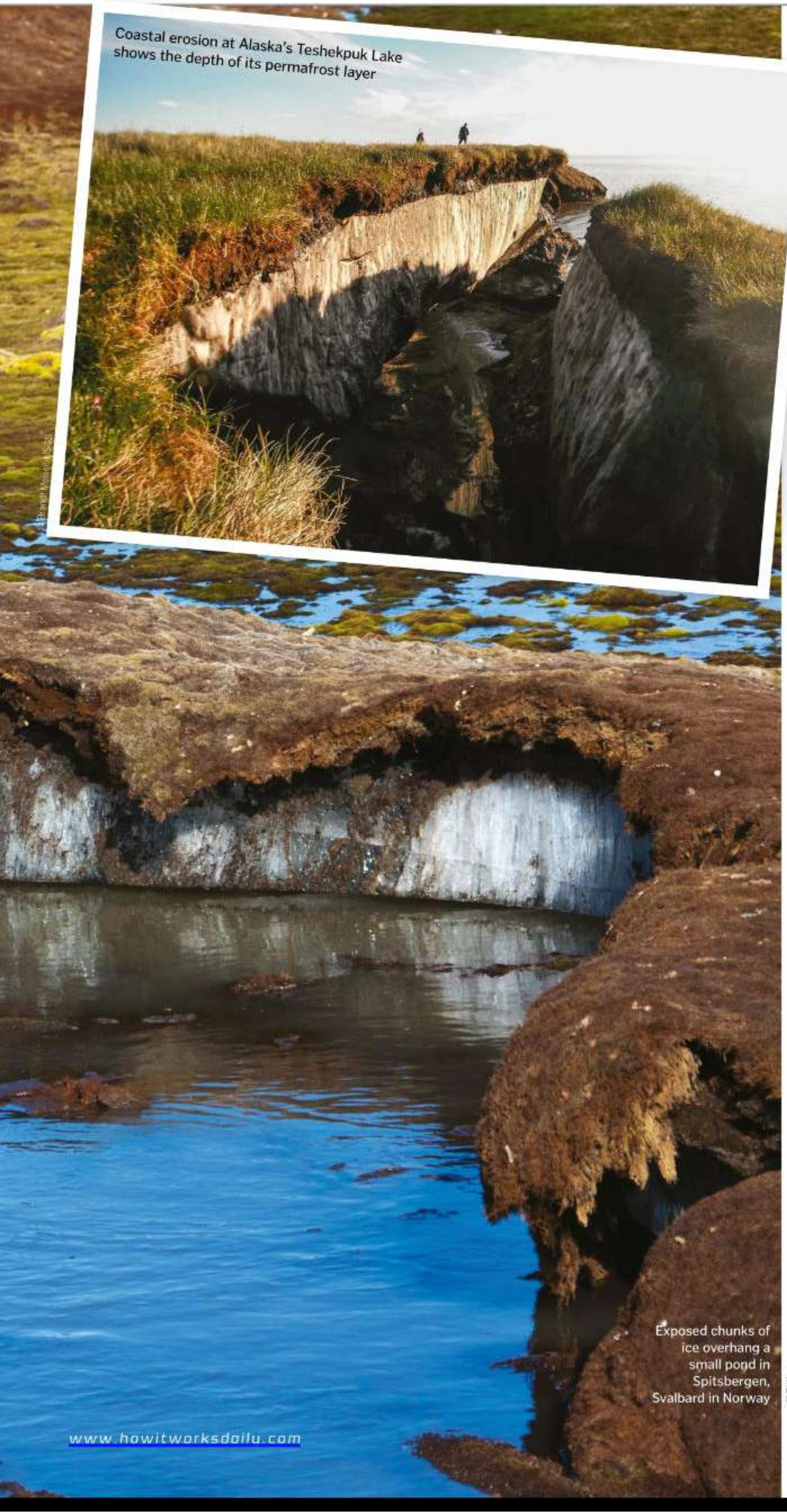
Melting permafrost on Herschel Island is risking cultural sites there. The region is experiencing the greatest rise in annual temperatures in the world.

Svalbard's 'doomsday' vault contains seeds to conserve the planet after a catastrophe, but melting permafrost could put the Earth's emergency supplies at risk.

Exposed permafrost in Norway melting. Melting permafrost helps release carbon dioxide and methane into the atmosphere.

Permafrost is essential to the maintenance of lakes. Regions with permafrost will be transformed as the world heats up.

"We have little information about their physiology and metabolic demands. We can't be sure what will happen if they begin to feast on all the carbon-filled organic matter frozen beneath them"



Coastal erosion at Alaska's Teshekpuk Lake shows the depth of its permafrost layer

Exposed chunks of ice overhang a small pond in Spitsbergen, Svalbard in Norway

area will be threatened, there may also be consequences for the entire planet. The Arctic takes up more carbon than it makes, so we call it a carbon sink. The plants that grow throughout the continent suck up carbon from the air in photosynthesis. If the Arctic gets hot enough to thaw permafrost, it could become a source of greenhouse gases. This could be the point of no return for the planet. Extra hydrocarbon release would lead to increased warming, which in turn would cause more hydrocarbon expulsion from melting ice. As much as 1.4 trillion tons of these gases could be locked up in permafrost.

Half of the organic material buried in the Earth's soil is frozen. A temperature increase of just a few degrees could melt permafrost and allow the plant and animal remains to break down. Earth has warmed up by 0.8 degrees Celsius since 1880 - and estimates suggest that a temperature increase of just one degree Celsius could jeopardise more than a quarter of the planet's permafrost.

Frozen layers examined

The surface of permafrost is called the active layer. This bit at the top thaws and freezes again every year. The topsoil can be a mere dusting on the ground or reach five metres in depth, and is rich in bacteria. One gram of soil might hold more than 1 billion microbes. Most of these microscopic organisms cannot be grown in lab conditions, and we have little information about their physiology and metabolic demands. We can't be sure what will happen if they begin to feast on all the carbon-filled organic matter frozen beneath them.

Ice wedges are described as 'massive' when their frozen water content reaches 250 per cent. These are the result of existing liquid reservoirs under the ground or an amalgamation of water from precipitation and surface flow. As temperatures rise, less and less of the permafrost survives to the next winter. The active layer is getting thicker as the ice beneath retreats, and the coldest areas of permafrost are heating the quickest.

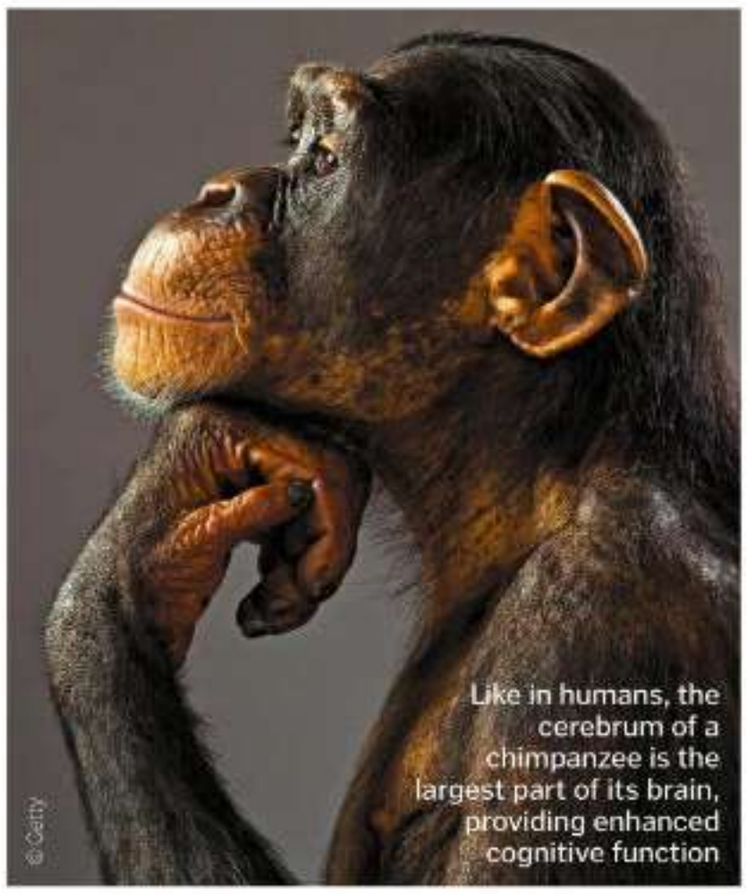
The ground transitions from a fertile upper layer to solid ice buried underneath

Animal brain anatomy

When it comes to what's between our ears, some animals are surprisingly similar to us

The animal kingdom is filled with brainy beasts, each with their own intelligence adapted to their way of life. Each of the five groups of animal to have a spine, known as vertebrates, has a brain. As a condensed collection of electrically stimulated nerve cells, this organ is the control centre for an animal's entire body, operating its senses, instincts and behaviour. However, when it comes to their brains, it's not a case of one size fits all. Fish, amphibians, reptiles, mammals and birds have evolved brains with a similar function, but they vary in form.

There are four distinct areas of the vertebrate brain: the cerebrum, optic lobe or tectum, cerebellum and medulla oblongata. The brains of different vertebrate species each have different regions that are larger and more complex than in other animal groups. For example, the optic lobe in bony fish is proportionally larger than any other animal group. Evolved to spend their lives in water, their survival depends on the ability to be aware of their surroundings. Therefore, having more brainpower to process visual information is vital. However, in mammals this region of the brain is minute, and its function has been integrated into the cerebrum.



Like in humans, the cerebrum of a chimpanzee is the largest part of its brain, providing enhanced cognitive function

As the most advanced in terms of cognitive ability, mammals possess a large cerebrum, the site of more complex neural and sensory functions. Some species have evolved the ability to become self-aware, such as apes. This is due to the vast amount of neurons packed into their enlarged cerebrum. The folds in these are important as they increase the surface area, allowing a greater number of neurons to process more information.

Inside the animal mind

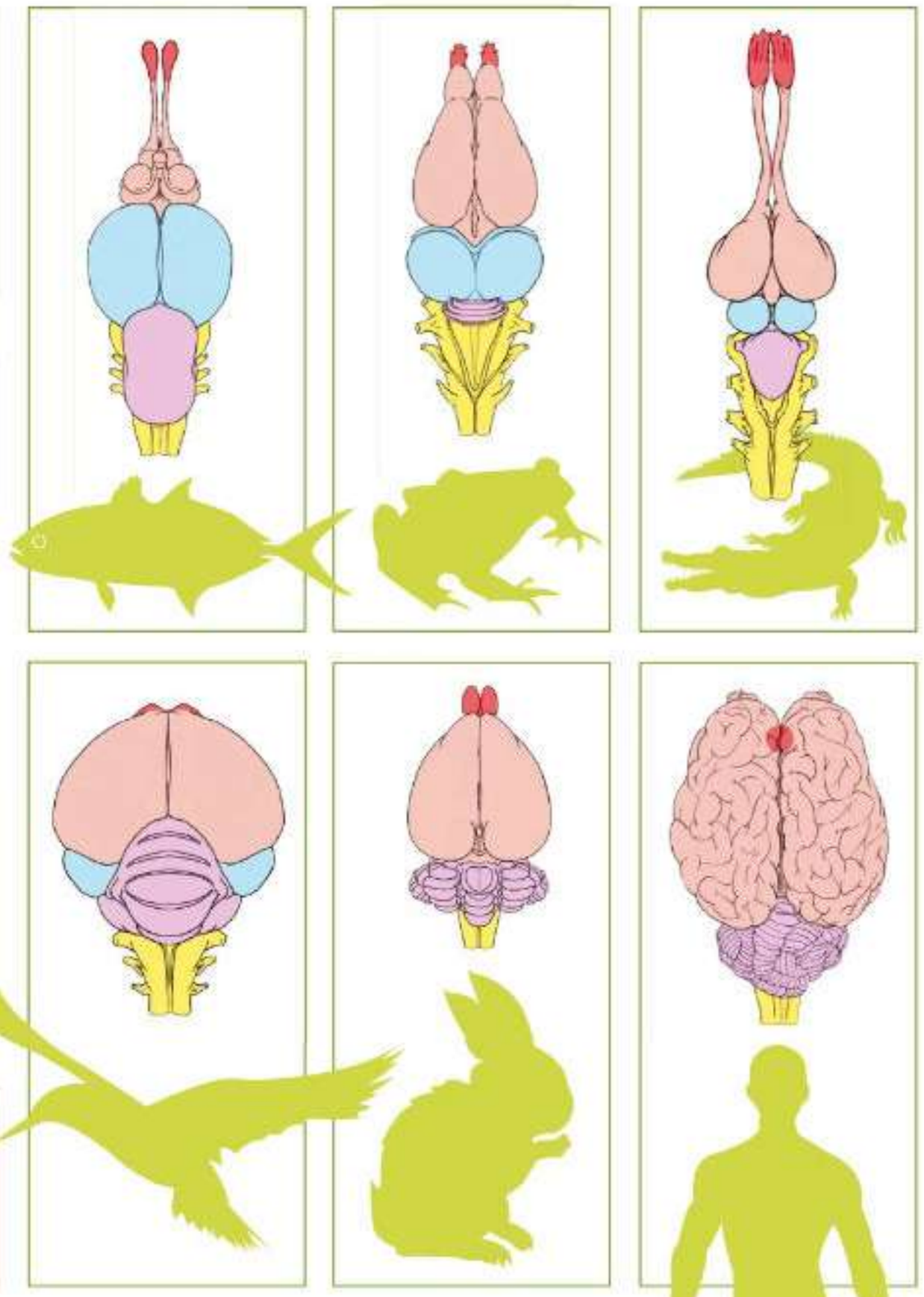
Cerebrum
The cerebrum is the information house. It stores, processes and translates neurological information involved in voluntary movement, sensory information, communication and memory.

Optic lobe
Within the midbrain, these lobes play a vital role in visual information processing.

Cerebellum
This region of the brain assists with the animals' motor skills, such as walking and coordination.

Medulla oblongata
As the point where the brain stem merges with the spinal cord, the medulla oblongata regulates heart rate, respiration and also blood pressure.

Olfactory bulb
This is the site of smell translations – a vital ability in the animal kingdom for detecting food and being alerted to danger.



Brainless beasts

Not all animals are blessed with brains – but don't be fooled, they're no dummies and have evolved this way to survive their environments. Beneath the ocean waves, many marine species are missing the collection of grey cells we call a brain. Instead, a network of neurons and sensory cells, spread throughout their bodies, enable these creatures to navigate the waters, sniff out food and protect themselves against predators. Jellyfish and starfish are some of those without the assistance of a central nervous system. Instead they have a net of nerves throughout their bodies that respond to stimulation by touch, temperature and salinity.

At the tip of each limb, starfish have light-receptive cells to indicate large masses such as coral reefs

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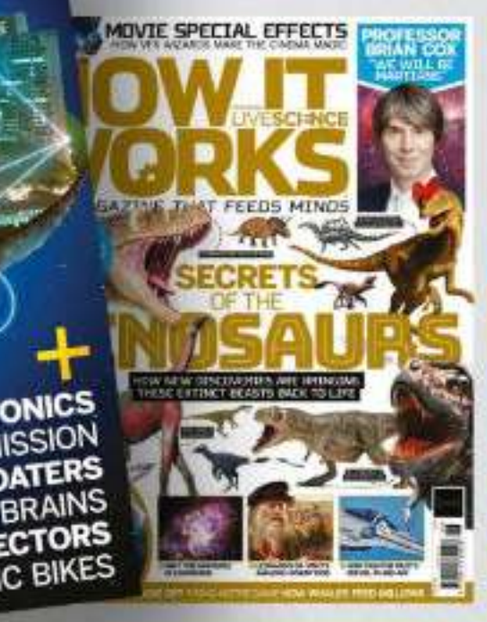

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HUMAN HABITATS ON MARS

To survive on Mars, we'll need something to live in. Could these homes be the answer?

Words by **Jonathan O'Callaghan**

For decades, sending humans to Mars has been one of the main goals of our space exploration endeavours. Countries like the US and China, and companies such as SpaceX have all expressed a desire to colonise the Red Planet. But to do so, we will also need a way for humans to survive – and thrive – on the surface of this hostile world. And efforts have been long underway to do just that, by designing habitats that humans may live in.

Building a habitat on Mars poses particular challenges that are not faced anywhere on Earth. First there is the lack of pressure – about one per cent of Earth's at sea level – which means habitats must be pressurised. There are also vast temperature swings, from 20 degrees Celsius to as low as -153 degrees Celsius as day turns to night and the Sun's heat escapes through the thin atmosphere. A lack of obvious resources like building materials and water also poses a significant challenge, as does coping with less sunlight – about 44 per cent less than we experience here on Earth.

Entertainment will be important on Mars to stop the astronauts from getting bored

To overcome some of these challenges, NASA has been running the 3D-Printed Habitat Challenge since 2015, to see if anyone can come up with viable solutions to these problems. 3D-printing is deemed to be one of the best ways to build habitats on Mars, reducing the amount of mass that will need to be carried to the surface – especially if we can use Martian resources to print them.

In May 2019, two teams were awarded a combined $700,000 (around £580,000) to further develop the ideas they had suggested – one from New York-based AI SpaceFactory, called MARSHA, and another, Den@Mars, developed by Pennsylvania State University. Both make use of a curved structure in order to reduce the pressures on the habitat while on Mars. But while Den@Mars is a more traditional dome, MARSHA is a cylindrical shape – one of the factors that earned it the top prize from NASA of $500,000 (around £415,000), after successfully printing a one-third scale model of the design in 30 hours almost completely autonomously.

NASA hopes that these designs, or some variant of them, may form the basis of eventual Mars habitats when humans land there at some point in the 2030s or later. Many challenges remain, however, not least working out how to actually land the equipment on Mars that could print these structures, and ultimately sending humans there too. But if some of these challenges can be overcome in the near-term, it raises the prospect of eventual missions in the future.

The walls of the MARSHA habitat will be layered to block radiation and provide insulation

Mars materials

To build a habitat on Mars, MARSHA will use materials directly from the surface of Mars to reduce the amount of resources that need to be carried from Earth. The habitat will be built using basalt fibre extracted from the Martian rock, combined with a renewable bioplastic called polylactic acid (PLA) that can be processed from plants grown on Mars.

The resulting material has a similar strength to carbon fibre yet is much easier to make, while the plastic is a great shield against cosmic radiation. Using PLA also ensures the material is recyclable, and it will not expand and contract too much as temperatures on Mars change. The idea is that a machine on Mars, like a large crane, will be able to use this material to autonomously produce the habitats for astronauts to live inside, once the resources have been produced on the surface.

MARSHA habitats can be built on Mars to house many astronauts

"Building a habitat on Mars poses particular challenges"

The interior of the habitats will be fairly open and bright, promoting the astronauts' circadian rhythms

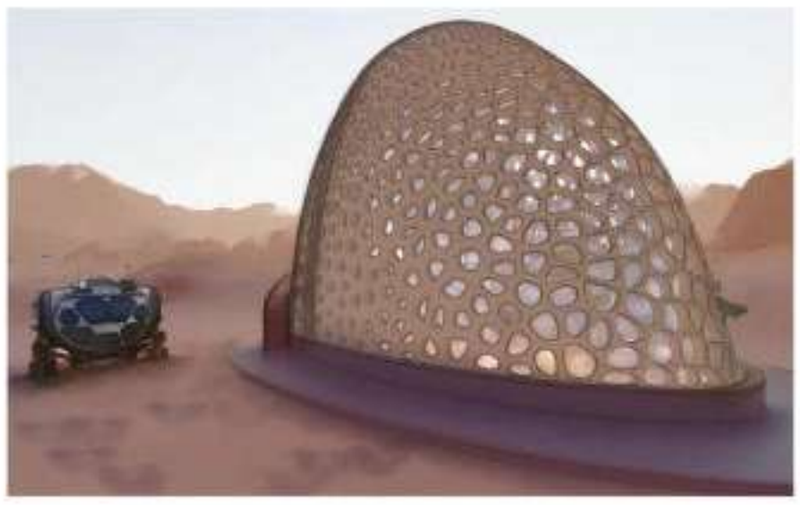
© Al SpaceFactory

Martian houses

Here are some of the other designs in NASA's Mars habitat competition that were considered

Team Kahn-Yates

This team from Jackson, Mississippi, designed a Martian habitat with a mottled design, that can cope with dust storms and the harsh climate on Mars.



© Team Kahn-Yates

Den@Mars

This idea from Pennsylvania State University planned to use digital scanning and a nozzle to squirt out a paste-like substance to produce a dome-shaped structure.

© Den@Mars

5 FACTS ABOUT LIVING ON THE RED PLANET

1 Lower gravity
Mars has just 38 per cent of Earth's gravity, so astronauts on Mars will need to exercise regularly to overcome any loss in bone density and muscle mass.

2 Space radiation
The thinner atmosphere of Mars means that astronauts will be exposed to much more solar and cosmic radiation, and must remain protected on the surface.

3 Launch windows
Owing to the orbits of Earth and Mars, missions between the two can only be launched every 26 months, and it will take about eight months to make the journey.

4 Martian water
Water cannot exist as a liquid on Mars because of the low pressure. But it's thought to be frozen under the surface as ice, which could be used by astronauts.

5 Life on Mars?
It's possible that Mars could play host to some form of microbial life. And perhaps it will take astronauts going there for us to find out for sure.

Team SEArch+/Apis Cor

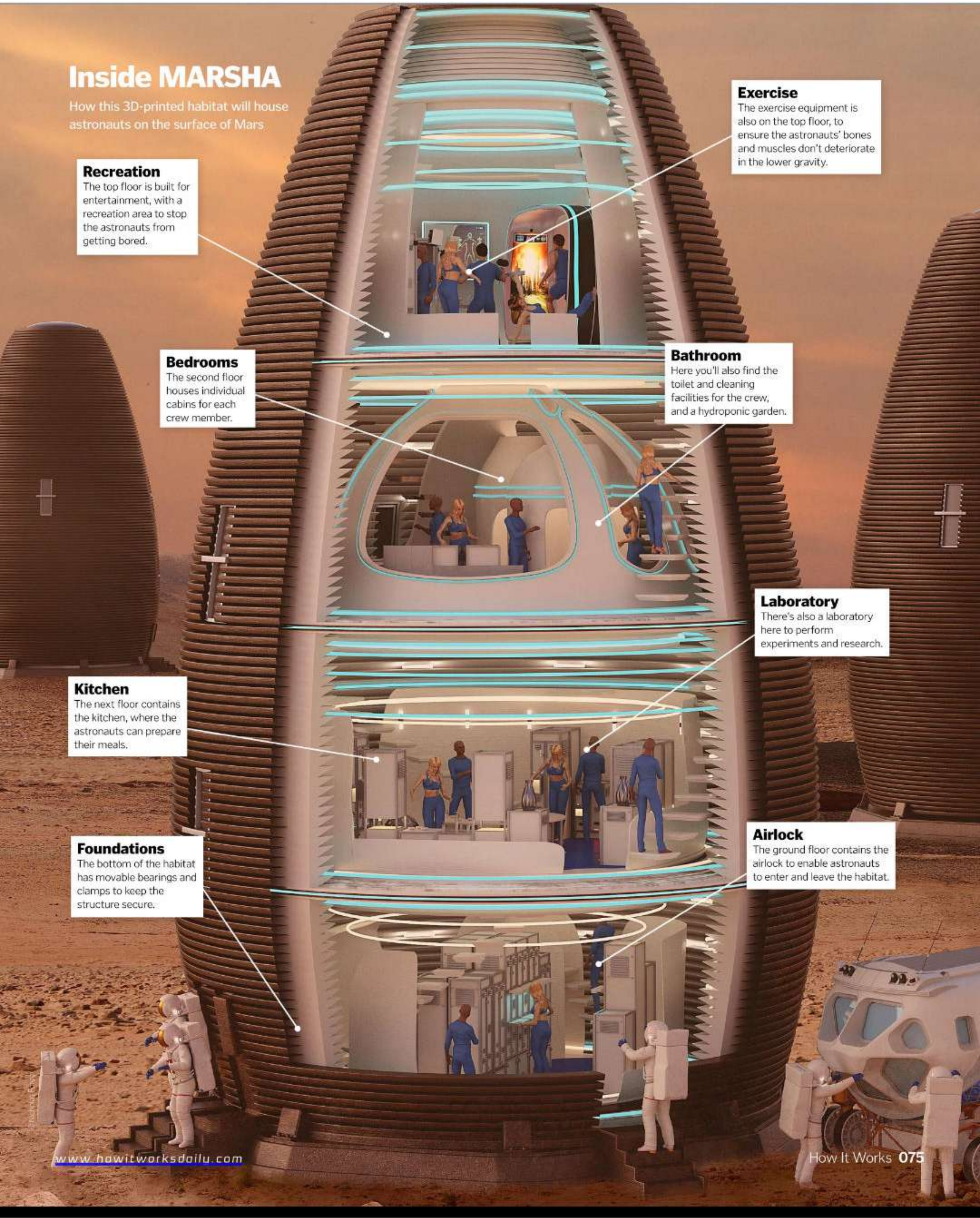
The swooping design for this idea uses the soil of Mars to protect astronauts inside from deadly radiation.

© SpaceX

DID YOU KNOW? *Elon Musk's SpaceX company wants to have 1 million people living on Mars by the end of this century*

Inside MARSHA

How this 3D-printed habitat will house astronauts on the surface of Mars



Recreation
The top floor is built for entertainment, with a recreation area to stop the astronauts from getting bored.

Exercise
The exercise equipment is also on the top floor, to ensure the astronauts' bones and muscles don't deteriorate in the lower gravity.

Bedrooms
The second floor houses individual cabins for each crew member.

Bathroom
Here you'll also find the toilet and cleaning facilities for the crew, and a hydroponic garden.

Laboratory
There's also a laboratory here to perform experiments and research.

Kitchen
The next floor contains the kitchen, where the astronauts can prepare their meals.

Airlock
The ground floor contains the airlock to enable astronauts to enter and leave the habitat.

Foundations
The bottom of the habitat has movable bearings and clamps to keep the structure secure.

Exploring the giant moon of Saturn

NASA's Dragonfly space mission combines incredible scientific potential with innovative technology

NASA is always pushing the boundaries of space exploration, looking for new and innovative methods to explore worlds that could explain how life arose on Earth, or our place in the universe. Now, thanks to NASA's New Frontiers Program – whose other missions include New Horizons, Juno and OSIRIS-REx – the Dragonfly mission will be exploring Saturn's largest moon, Titan, by 2034.

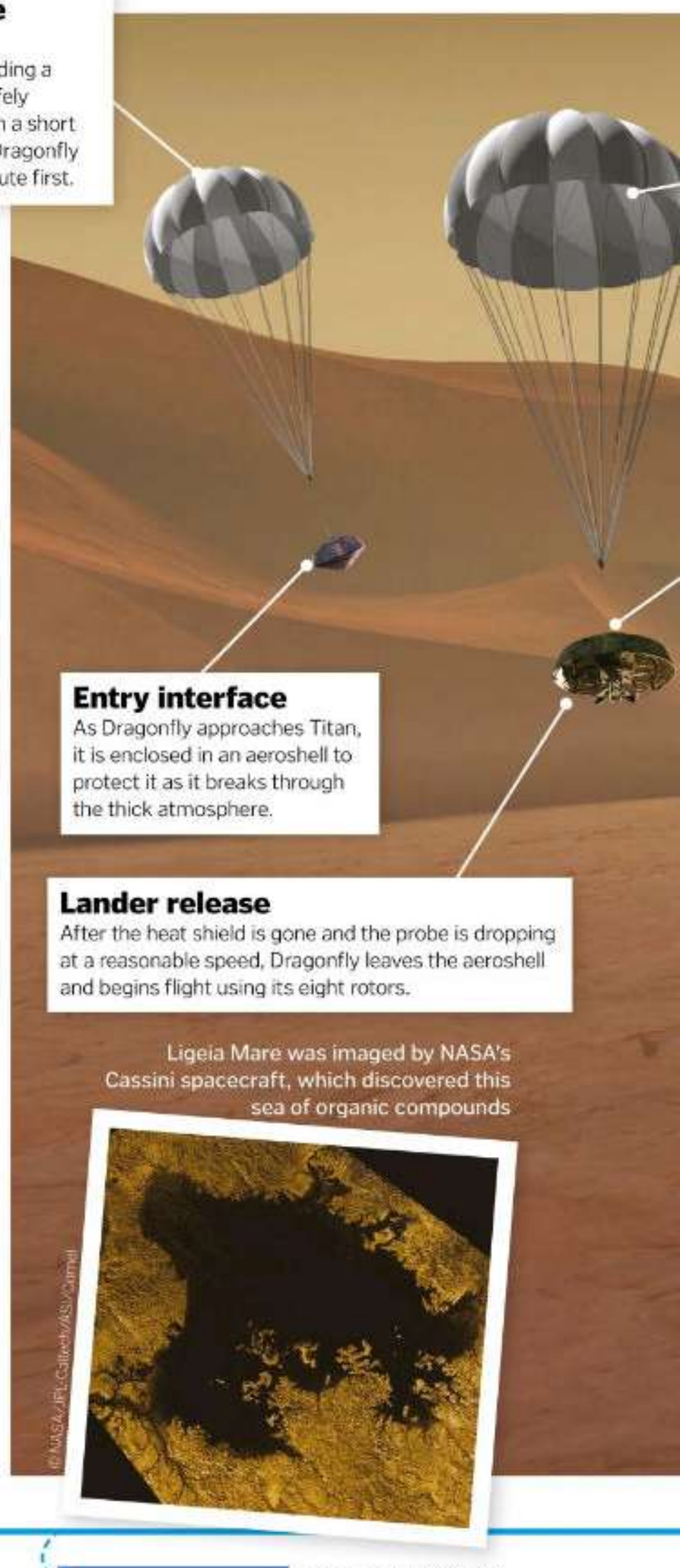
Dragonfly will be built and operated by a team at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, US, and will utilise the multiple-rotor capabilities of the drone to conduct important scientific missions on an exciting ocean world, which isn't dissimilar from what Earth was like billions of years ago.

There are many reasons why Titan was chosen as the next target, but these would not have been known if the Cassini-Huygens mission had never visited the moon. The Cassini mission revealed lakes and oceans of liquid methane on Titan, a dense, nitrogen-rich atmosphere and a hydrological cycle of clouds and rain – all remarkable comparisons to a young Earth, before the development of biology.

Organic molecules, such as methane, are complex molecules consisting of a carbon atom combined with hydrogen, oxygen and nitrogen. We know methane to exist on Earth as just a gas. However, Titan orbits Saturn at a distance of about 1.4 billion kilometres from the Sun, roughly ten times further than Earth, and has a surface temperature of around -179 degrees Celsius. In these conditions, liquid water would immediately freeze, but methane has a much lower freezing temperature so exists there in liquid form.

> *"The Cassini mission revealed lakes and oceans of liquid methane on Titan"*

Now that scientists have seen this world of flowing organic material, which is known to be a key component for life as we know it, they are determined to get beneath the atmosphere that has masked all its alluring secrets, and try to find out about Earth's past in the process.



Drogue chute deployment
The challenge of landing a space probe is to safely decrease its speed in a short time, which is why Dragonfly deploys a drogue chute first.

Entry interface
As Dragonfly approaches Titan, it is enclosed in an aeroshell to protect it as it breaks through the thick atmosphere.

Lander release
After the heat shield is gone and the probe is dropping at a reasonable speed, Dragonfly leaves the aeroshell and begins flight using its eight rotors.

Ligeia Mare was imaged by NASA's Cassini spacecraft, which discovered this sea of organic compounds

© NASA/JPL-Caltech/ASI/Cornell

EXPLORING TITAN

January 2017
NASA begins planning for the fourth mission of its New Frontiers Program, following on from the New Horizons, Juno and OSIRIS-REx missions.

© NASA/JPL-Caltech

September 2017
NASA's Cassini mission ends, closing the curtain on this valuable source of up-close scientific data about Titan.

December 2017
NASA narrows down the choice of missions to Dragonfly and CAESAR, a sample-return mission to comet 67P/Churyumov-Gerasimenko.

© Johns Hopkins APL

January 2018
Aerospace engineers at Pennsylvania State University, US, build and develop the Dragonfly rotorcraft.

Where will it land?

Not only did the Cassini-Huygens mission tell us a lot about Titan's environment, it was also able to mark out areas of the moon that are most useful to science. These are the highest priority areas for a visit by Dragonfly. The rotorcraft will first land in a region called Shangri-La, a dune field near the moon's equator. This bears comparison to the dunes in the Namib Desert, southern Africa.

The Earth-based team will then assess Dragonfly's true flight capabilities with a series of 'leapfrog' flights of up to eight kilometres, before moving on to the 80-kilometre-wide Selk impact crater. This crater has shown evidence of past liquid water, organic materials and energy, which together are essential for the existence of life.

The Shangri-La region was also visited by ESA's Huygens in 2005

© NASA/JPL/Space Science Institute

Gliding onto the scene

How Dragonfly's unique rotorcraft design will allow it to visit multiple sites on Titan

The central image shows Titan in visible light. The surrounding images show the moon in infrared

Main chute deployment
The main parachute then deploys after the drogue chute has stabilised the craft.

Heat shield separation
At a distance of about 3.8 kilometres above the surface, the heat shield that has protected Dragonfly so far is jettisoned.

Moving on
Once the next site is determined, the eight rotors will power up again, enabling the lander to move on to other locations.

Powered flight
Dragonfly then flies to its landing site, in this case the Shangri-La dunes.

High-gain antenna release
After a safe landing, Dragonfly's high-gain antenna deploys and enables communication to resume with the Earth-based team.

Touchdown on Titan
Dragonfly's onboard sensors identify a safe and suitable landing site from a low altitude.

5 FACTS ABOUT EXPLORING TITAN

1 The first manmade visitor
NASA's Pioneer 11 spacecraft was the first to explore Titan in 1979. Scientists at the time thought (incorrectly) that Titan was the largest moon in our Solar System.

2 Making it snow
Titan's clouds are full of methane, but other organic compounds form in the atmosphere and fall like light snow onto the moon's surface.

3 Investigating the surface
Dragonfly will have different spectrometers onboard that will determine the surface composition at dozens of locations on Titan, which will characterise its prebiotic chemistry.

4 Familiar sights
Some areas on Titan are analogous to areas on Earth. For example, some of Titan's dune fields are similar to dunes in the Namib Desert.

5 Treading lightly
Titan has a diameter of 5,150 kilometres, just larger than Mercury, and has a surface gravity that's just one-seventh of Earth's.

June 2019
NASA confirms the Dragonfly mission as the winner and Titan as the next host of another exhilarating expedition.

2026
The Dragonfly space probe begins its voyage – an eight-year journey to the outer Solar System.

2034
The space probe faces its biggest and most dangerous test – landing safely on the moon.

2036/2037
The planned mission for Dragonfly ends, after a duration of 2.7 years exploring multiple sites around the ocean world.

How will the drone fly?

Since the 1990s, aerial mobility has been in increasing demand on Earth, which has led to the evolution of drones. Now this mission will use a drone for the exploration of a moon over 1 billion kilometres away.

Titan has low gravity and an atmosphere four times as dense as Earth's. This makes it easier for Dragonfly to fly using its eight rotors, travelling around 175 kilometres across the surface over a three-year-long mission. It's further than any Mars rover has travelled. Due to Titan's thick atmosphere and distance from the Sun, it's not possible to use solar power, so the drone will use a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), like the one on the Curiosity rover.

Dragonfly is a 'rotorcraft' – its eight rotors will enable it to fly on Titan

MEGA CREEPY-CRAWLIES

Meet the giant prehistoric creatures that once roamed the Earth hundreds of millions of years ago

Words by **Scott Dutfield**

350 million years ago the Earth was covered in dense forest that was a perfect habitat for giant creepy-crawlies. Arthropods are a collection of invertebrates with jointed limbs – creatures such as spiders, crabs and insects that sport an exoskeleton and a segmented body. First appearing around 545 million years ago, during their evolution this animal group has diversified to make up around 80 per cent of all known species on Earth.

However, the small arthropods of today are a fraction of the size of their ancestors, which once grew up to several metres long. The era of the giant arthropods began during an explosion of life in the Cambrian Period, when these giants lived in the world's oceans.

Over millions of years the surface of the Earth became more lush with vegetation. An increase in plant life brought a richer oxygen atmosphere, a key ingredient for supersizing arthropods. By the time of the Carboniferous Period (from about 360 to 299 million years ago), oxygen made up 35 per cent of the atmosphere, compared to the 21 per cent we currently have in the atmosphere today.

Mega millipede

Scurrying through the dense foliage of a Carboniferous forest 340 million years ago was once a colossal millipede. At around 2.6 metres in length, Arthropleura is perhaps the biggest arthropod to crawl across the planet.

Much like its modern-day descendants, it is believed to have been a herbivore. Although the mouth of an Arthropleura has never been found to assess the presence of carnivorous teeth or mandibles, its fossilised faeces and digestive tract revealed spores of plants.

By the start of the Permian Period (300 million years ago) the world's oxygen levels had begun to decline. In a domino effect, the reduction of oxygen resulted in reduced plant growth. Not only vital as a food source and oxygen provider, the lush vegetation also provided moisture. Arthropleura is thought to have been starved of atmospheric hydration and dried into extinction 290 million years ago.

Fossilised track marks indicate Arthropleura's prehistoric movements

© Michael C Rigal

© Alamy

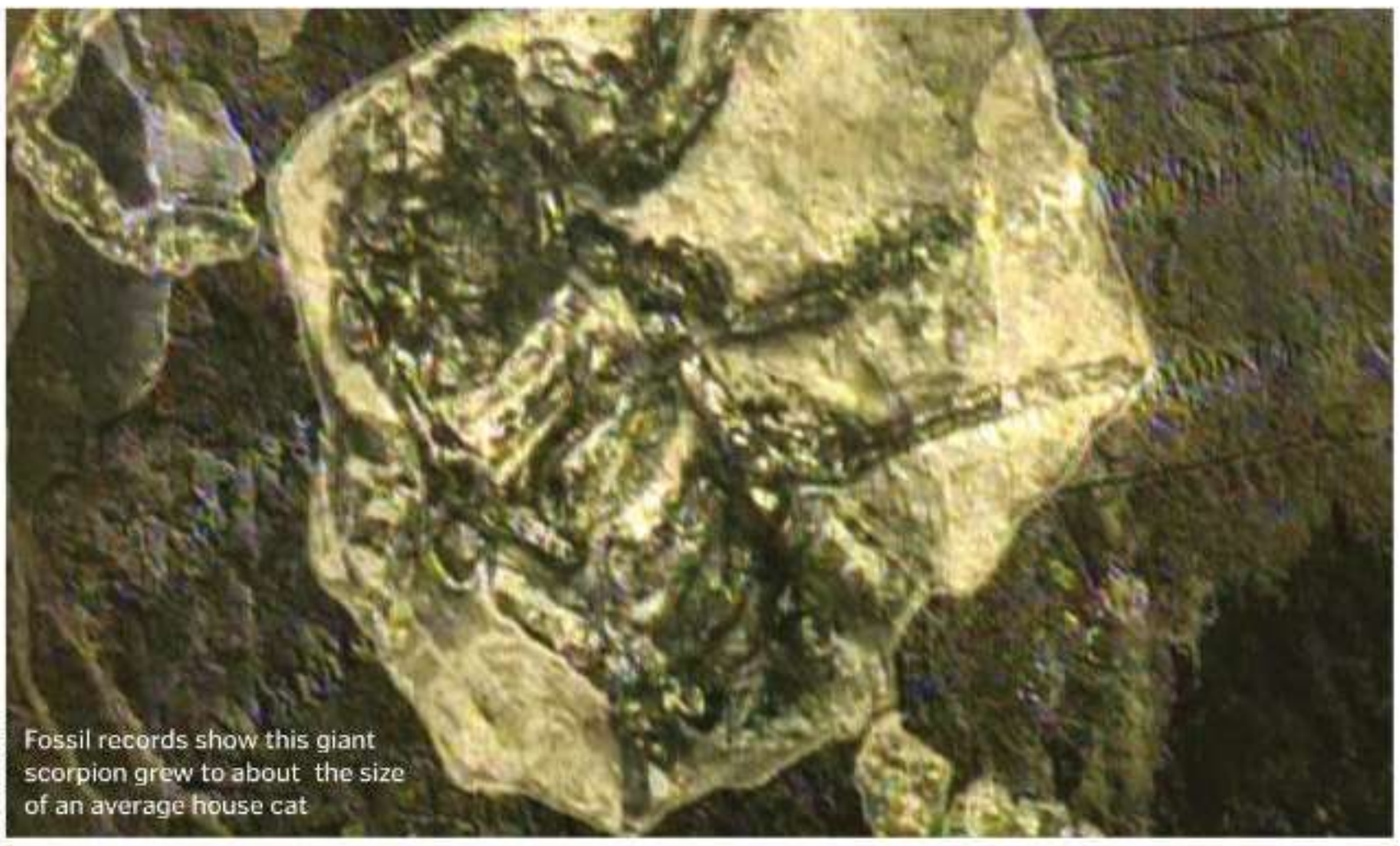
Completely encased by its exoskeleton, this two-metre-long millipede was an armoured giant

Supersized scorpion

As the true scorpion king *Pulmonoscorpius kirktonensis* dominated the arachnid scene, with an exoskeleton spanning 70 centimetres from pincer tip to tail sting.

Roaming through Carboniferous marshland and forests, this giant scorpion is commonly referred to as the 'breathing scorpion' due to the evolution of a book lung to breathe air. Much like the pages in a book, a series of plates formed the scorpion's lungs, each richly supplied with blood to exchange oxygen and carbon dioxide.

It's believed that this prehistoric eight-legged predator feasted on the flesh of other arthropods and small amphibians. In typical scorpion style, Pulmonoscorpius was equipped with a mighty sting, also known as a telson. However, without coming face to face with one the potency of its venom will never be known. Using research conducted on modern-day scorpions, scientists have deduced that there is a relationship between pincer size and venom strength – the larger the pincers the weaker the sting, and vice versa. Considering Pulmonoscorpius had relatively small pincers for its body size, a sting from this giant scorpion must have packed a serious punch.



Fossil records show this giant scorpion grew to about the size of an average house cat

© Shutterstock

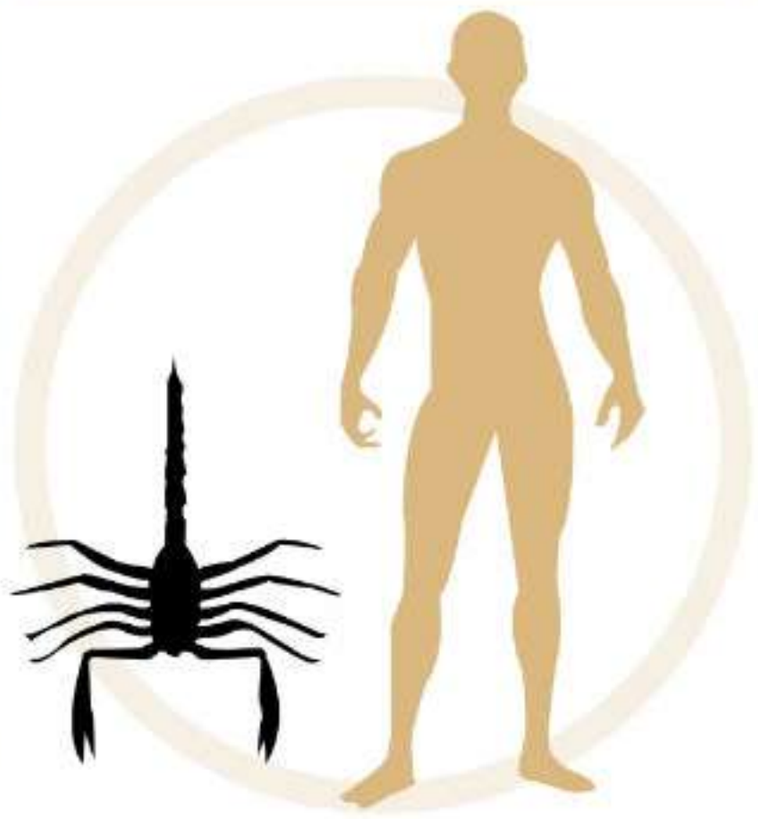
Trilobite monarchs

Covering the seafloor, trilobites were once a common sight in our oceans, and they frequently appear in fossil beds around the world today. These prehistoric woodlouse-like creatures, like so many other marine arthropods, burst into existence during the Cambrian explosion and trawled the ocean floor for food, until their extinction during the Permian Period several hundred million years later.

Trilobites varied in size, and a common species, *Elrathia kingii*, grew to only a few centimetres in length. One species, however, has overshadowed the rest in size. With an exoskeleton that measured around 70 centimetres, *Isotelus rex* was once a benthic behemoth. Fossil evidence found in Canada places these marine giants during the Ordovician Period, some 480 million years ago.

© Mike Beauregard

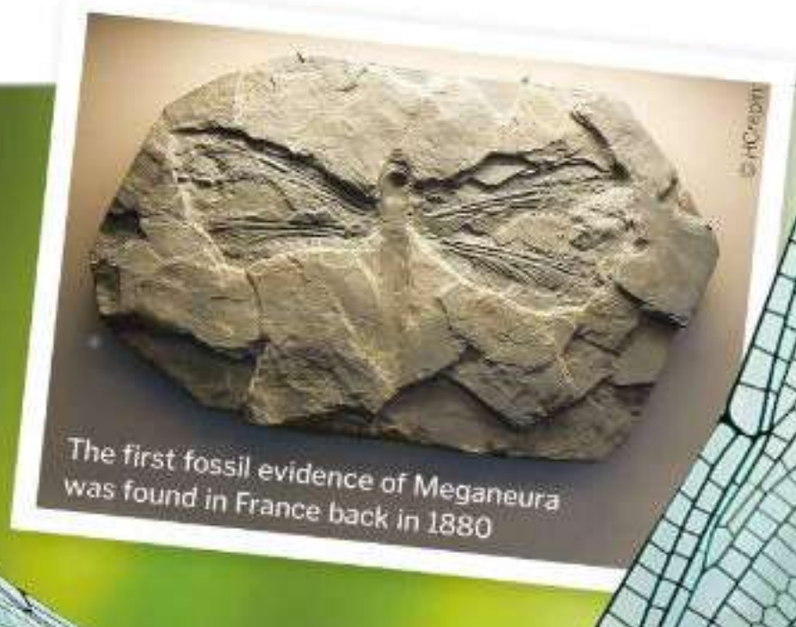
As the largest known Trilobites, *Isotelus rex* dominated the seafloor



Immense dragonfly

Today's dragonflies can be hard to spot as they zip above the surface of a lake or pond. However, travelling back to the Permian Period, around 290 million years ago, you would have to duck to dodge a passing dragonfly. Known as Meganeura, this genus of giant insect had a wingspan of around 75 centimetres. Much like its comparatively tiny descendants, these winged giants also used tooth mandibles to snap prey from the air.

As more and more amphibious species evolved from water, food for these giant carnivores became bountiful. However, like all other megabugs facing the end of this period, climate change claimed the land, destroying Meganeura's habitat and food supply and wiping them from the skies.



The first fossil evidence of Meganeura was found in France back in 1880

Meganeura had a wingspan of 75cm – around the same as a tawny eagle

Living giants

Although not a member of the arthropod family, *Campanile giganteum* is a prehistoric creeper that once crawled across ocean floors. With a shell stretching over one metre long, this massive snail was one of the largest gastropods of its kind. *Campanile giganteum* lived in the Eocene Epoch, 56–33.9 million years ago.

Unlike the mega arthropods, the descendants of these giant snails have maintained a significant size to the present day. Found in Australia's southwest shallows, *Campanile symbolicum* is reminiscent of its ancestor, sporting a conical shell between six and 24 centimetres long.

It's unclear how this giant snail's body appeared, as soft tissue is rarely able to fossilise

"This genus of giant insect had a wingspan of around 75cm"

Giant ant army

In 2011 a team of archaeologists uncovered the fossilised remains of a new species of giant ant that rivalled the size of a hummingbird. Found at a quarry in Wyoming, US, Titanomyrma (giant ant) was a prehistoric insect that measured five centimetres in length. Now known as *Titanomyrma lubei*, these giant winged ants are thought to have roamed Earth around 50 million years ago.

Archaeologists studying the fossil specimens have hypothesised a link between similar prehistoric ants found in Germany, which suggests a possible pattern of migration from Europe to North America as a response to the era's changing climate.

Unlike many prehistoric mega creepy-crawlies, some species of ant have retained their supersized stature. Queens among *Dorylus wilverthi* ants are around the same size as Titanomyrma, and worker ants are just shy of that size by a couple of centimetres.

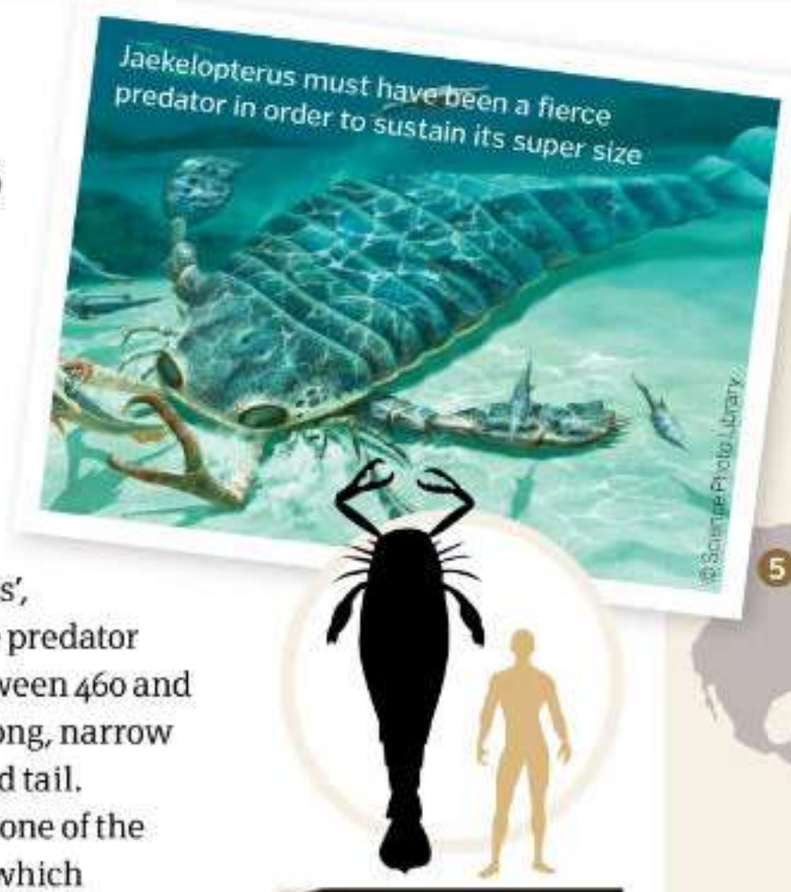
These giant ants once roamed the riverbeds of Wyoming, US

Sea scorpions

It's understood that the world's arthropods once dwelled exclusively beneath the waves – including scorpions. Before the giant Pulmonoscorpius roamed the forest, its ancestors scoured riverbeds in search of food.

Commonly called 'sea scorpions', Jaekelopterus was a giant marine predator during the Devonian Period, between 460 and 255 million years ago. It sported long, narrow claws, a flat, shrimp-like body and tail.

In 2007 researchers uncovered one of the Jaekelopterus's fossilised claws, which measured 46 centimetres, and led them to believe that the sea scorpions were around 2.5 metres in length. To support such a body, Jaekelopterus's meal portion sizes had to match. As it became difficult to compete for food against the increasing number of vertebrate species in the waters, over time these giants evolved into smaller species.




© Ghedigreco

The giant claws of this sea scorpion hint at its enormous original size

Around the world

Monster shrimp

Anomalocaris was another giant-sized arthropod that swam through the seas, not long before the time of the sea scorpion. Resembling more of a modern-day shrimp, it grew to around 1.8 metres in length.

Although armed with two toothed and armoured mandibles, it is unclear whether or not they were used for tearing apart the hard shells of passing Trilobites or simply as a way to manoeuvre food into its mouth. Computer modelling of fossil remains suggests that the pineapple-ring-shaped mouth of Anomalocaris would have been unable to close fully and was thus unable to break apart hard material such as exoskeletons, leading many to believe that these marine creatures could only digest soft foods such as worms.

Swimming the seas during the Cambrian Period, around 500 million years ago, Anomalocaris moved by undulating its segmented body and extending swimming flaps, which were also the location of gills.

Anomalocaris used extended parts of its exoskeleton as fins to swim through the ocean

© James St. John

© Science Photo Library

5 FACTS ABOUT JODRELL BANK OBSERVATORY

1 Preventing interference
Phones are prohibited on the Jodrell Bank site due to the sensitivity of the Lovell Telescope. Even the staff room microwave is shut away inside a metal box.

2 Jodrell Bank on TV
The site has appeared in programs such as *Hitchhiker's Guide To The Galaxy* and a 1981 episode of *Doctor Who*.

3 An 'unsung landmark'
The Lovell Telescope won the 'unsung landmark' competition, held by the BBC in 2006.

4 Becoming bigger and better
In 2001 its power was strengthened to give it a fourfold increase in resolution power.

5 Made from battleships
Parts of WWI battleships were used when building the Lovell Telescope. HMS Revenge and HMS Royal Sovereign became part of the telescope's altitude rotator bearings.

Jodrell Bank's Mark II radio telescope was used in conjunction with the Lovell Telescope to help pinpoint a new class of space-time warping objects

Bernard Lovell said that the Soviets tried to assassinate him in 1963 for helping to create a nuclear missile early warning system at Jodrell Bank

The world's first radio telescope

How Jodrell Bank Observatory was used to prove Einstein's theories and even spy on the Russians

Situated 30 kilometres south of Manchester, England, is a site dedicated to exploring the depths of space and enabling us to comprehend what lies beyond our planet. Home to four active radio telescopes, Jodrell Bank is owned by the University of Manchester and is best known for being the site of the Lovell Telescope.

This telescope is named after astronomer Bernard Lovell, who founded Jodrell Bank in 1945. Lovell discovered the quiet site, away from any radio interference, while looking for the perfect spot to study cosmic rays.

One of its first findings was in December 1945. Lovell's team detected echoes; not from cosmic rays but from shooting stars. This led to the discovery that meteor trails leave behind dust particles from comets orbiting the Sun.

Further use for the observatory came during times of international tension, when keeping tabs on what was going on in the sky had added value. Throughout the Cold War, Jodrell Bank was involved in tracking US attempts to overtake the Russians in the space race.

Since that early discovery, hundreds of scientists and engineers have worked in Jodrell Bank. Its extensive findings include discovering gravitational lenses. This new class of space object showed the warping of space-time around them, proving the theories of Albert Einstein over half a century before.

Today, the observatory is a leading radio astronomy facility and recently gained world heritage status on 7 July 2019, highlighting its importance in assisting our understanding of the universe.

The Lovell Telescope

Completed in 1957, the Lovell Telescope was the largest telescope in the world. The distinctive structure was built by Bernard Lovell and engineer Charles Husband. The telescope is used to survey radio emissions from other galaxies, as well as investigating meteors.

Days after the Lovell Telescope was assembled, it was used to track the missile that carried Sputnik 1 into orbit. The Ministry of Defence also secretly used it as a nuclear missile tracking station.

The Lovell telescope is currently the third-largest steerable radio telescope in the world, with a diameter of 76 metres and a mass of 3,200 tons.

Today, the Lovell Telescope remains one of the world's largest and most powerful radio telescopes

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BRAIN DUMP

Because enquiring minds need to know...

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LAURA MEARS


JAMES HORTON


JO STASS

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Could we make an artificial black hole?

Katie McClelland

Black holes have gravity that's so intense nothing can escape their grip. They can trap even the fastest particles – photons of light. In theory, it's possible to make mini black holes by causing high-energy particle collisions inside the Large Hadron Collider, but it hasn't happened yet.

Scientists elsewhere have been busy making artificial black holes to try and understand the real thing. Instead of using intense gravity, these artificial black holes use fibre optics and metamaterials to slow light down. The researchers hope that this might help us to work out what really happens at the event horizon. **LM**

The 'event horizon' is the border of a black hole. Once you cross, there's no turning back

© Getty

© Getty

Is raw always the healthiest way to eat a vegetable?

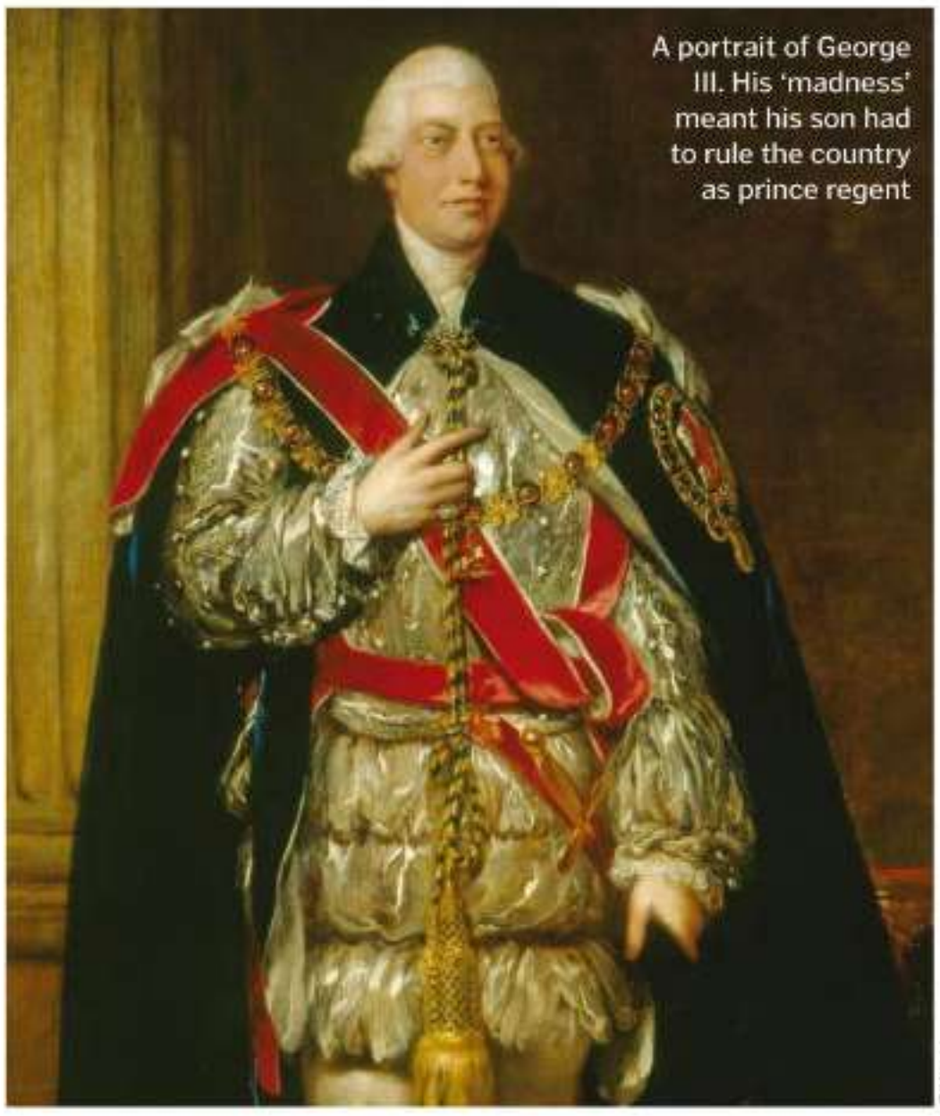
Liam Fausti

Cooking vegetables can destroy some vitamins, but it can also make some nutrients easier to digest. The exact effects of cooking on vegetable chemistry depend on the type of veg and the cooking method. Either way, the more vegetables you eat, the better. **LM**

Why was King George III 'mad'?

Theo Anderson

In his later life George III suffered bouts of 'madness'. The symptoms included hallucinations, convulsions, mental distress and babbling until he foamed at the mouth. For years, historians have blamed his symptoms on a blood disorder called porphyria, and the problem was perhaps made worse by the presence of arsenic in the medicine he was given. But recent research suggests he may have suffered from a mental illness like bipolar disorder, made worse by his poor general health. **TL**



A portrait of George III. His 'madness' meant his son had to rule the country as prince regent

© Wiki

© Getty

Which countries haven't adopted the metric system?

Jonny Sampson

The International System of Units, known as the metric system, is used by almost every country in the world, except for Myanmar, Liberia and the United States. **JT**

© Getty

Does Japan's emperor have much power?

Eric Alesio

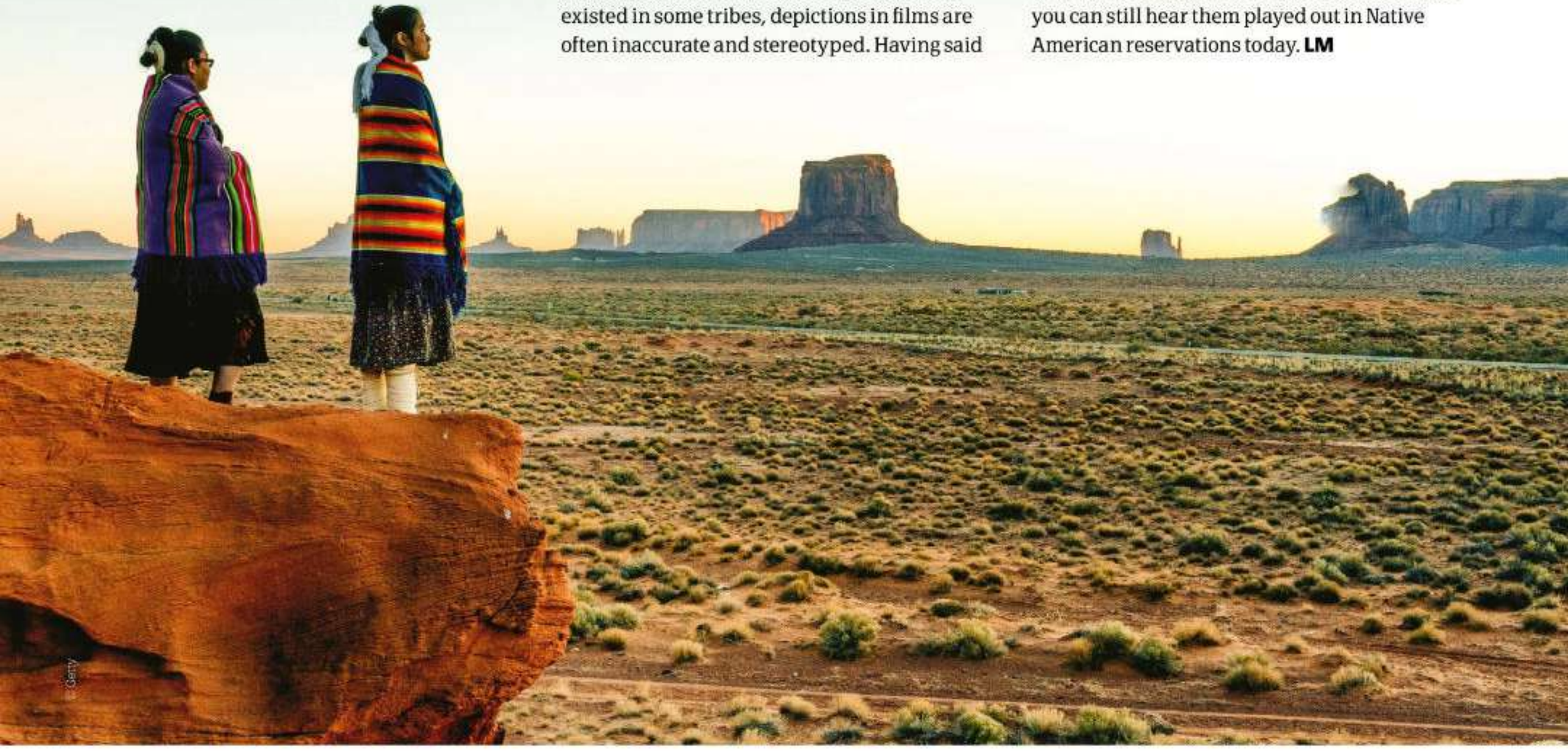
Historically there have been times when the emperor of Japan held great power. But since Japan's defeat in World War II, the role has been largely symbolic, with little political power. **JS**

BRAIN DUMP

Did Native Americans ever make that 'oo-ooo-oo' sound like in the movies?

Anastasia Vroom

Films often misrepresent Native American people and their cultures. Though war cries existed in some tribes, depictions in films are often inaccurate and stereotyped. Having said that, the Cherokee and Apache had war cries they would deploy to terrify their enemies, and you can still hear them played out in Native American reservations today. **LM**



Why can't I stop biting my nails?

Beata Jones

Scientists have many ideas about why people bite their nails, such as a way of dealing with anxiety, stress or boredom. However, there is no conclusive answer, meaning it probably has varied causes. **TL**

What is the most expensive coin in the world?

Jay Wheelock

The first dollar to be minted in the US, the 1794 Flowing Hair Silver Dollar, has a value of over $10 million (about £7 million). Experts believe it was the first dollar ever to be struck, meaning that President George Washington would have inspected it personally. **JT**

Why is the universe so big?

Susanna Rey

It's generally thought that the universe is roughly 93 billion lightyears in diameter. However, the universe is expanding, and because astronomers have different ideas of how fast this happens, it could be far larger. One recent analysis suggests the universe could actually be as much as 7 trillion lightyears across. **TL**

Real-life pirates were probably quite different to how they appear in books and films

© Getty

Did pirates really have peglegs and eyepatches?

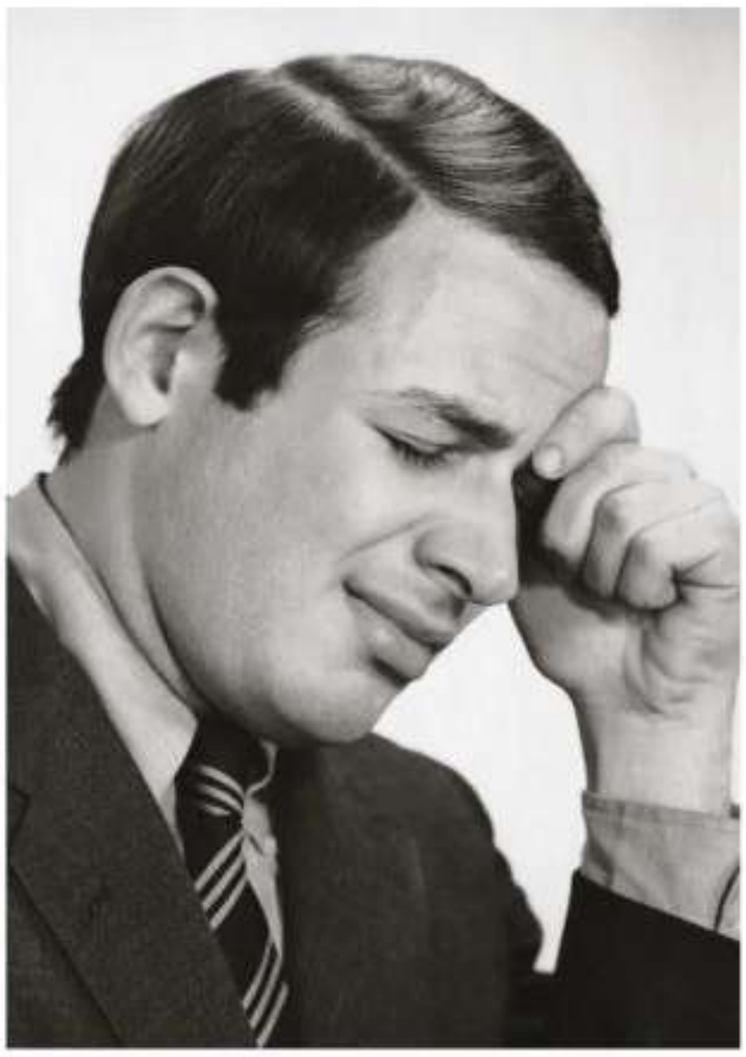
Ben Walsh

■ Pirates' fondness for peglegs and eyepatches has been exaggerated by films and books like *Treasure Island*. It's sometimes said that two-eyed pirates covered one eye with a patch to adjust the eye to see better in the dark, but there is little evidence for this. In the golden age of piracy it's also more likely that a pirate losing a leg would die of infection or blood loss, rather than survive to get a pegleg. Pirate life was brutal, and at least a few pirates used an eyepatch to cover an empty eye socket or had a wooden leg, but they seem uncommon. **JS**

Can I hurt my brain by thinking too hard?

Kristine Ng

■ It depends what you mean by hurt. Brains run on a simple sugar called glucose. Neuroscientists have shown that concentrating hard drains glucose from parts of the brain. This makes your brain fatigued, making it harder to concentrate and memorise, at least until the glucose level recovers again. You can also get tension headaches from focussing on a subject too hard, and stress from over-thinking can contribute to a range of health problems. However, as with many other parts of the body, it's often thought that exercising your brain is good for it, improving memory and other cognitive abilities. **TL**



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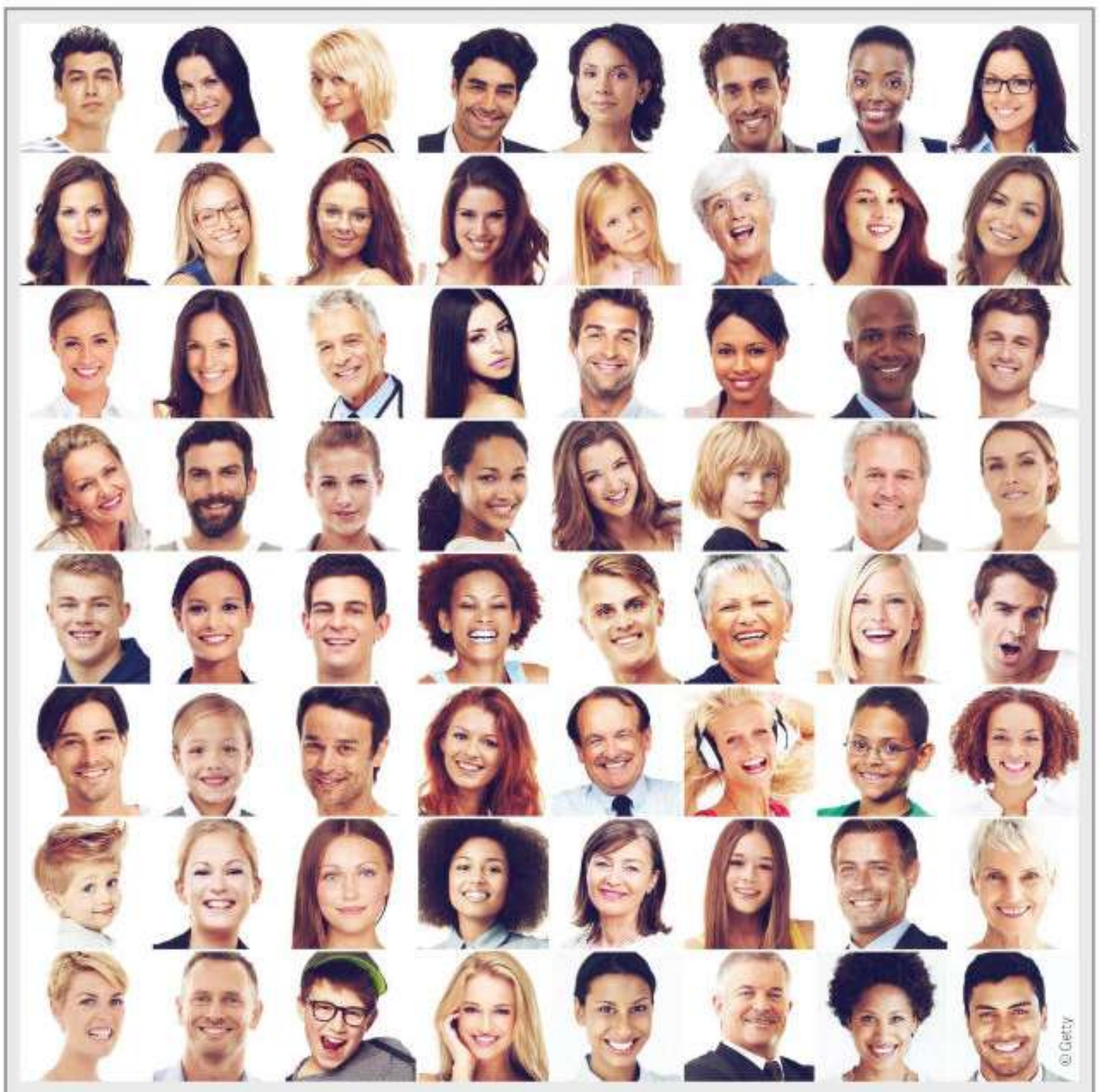

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What makes a pretty face?

Indra Khatri

■ Research suggests there are many factors for why people find a face attractive. Generally, people prefer faces that are more symmetrical, and seem to favour simpler faces, possibly because they are easier for the brain to process. Average faces that resemble many others in the population are also favoured, possibly because they hint at a more diverse set of genes. Much of it is also down to personal preference and the life experiences we have had. **JS**

BRAIN DUMP

Snorers' brains filter out the sounds of their own breathing

© Getty

Why don't loud snorers wake themselves up?

Raj Hart

■ Electrode studies of the human brain have revealed why loud snorers don't tend to wake themselves up: the brain goes into 'standby mode'. When we fall asleep, the frontal lobes start listening in on incoming noises. This part of the brain controls consciousness and problem-solving, and it works like an alarm system. It filters out safe background noises like our own snoring, and only wakes us up if we hear something loud, like a fire alarm or a baby crying. **LM**

© Getty

What happens when you pull a muscle?

Stef Ingham

■ Muscles are made up of thousands of fibres, and if they are overstretched or torn the result can be pretty painful. The medical term is muscle strain, and it's an extremely common sports injury, often occurring during sudden, explosive movements such as sprinting or jumping. The force can cause tissues to tear, partially or completely, and the recovery time depends on the severity of the damage. Doctors classify muscle strains into three grades, ranging from mild (less than five per cent of fibres affected) to severe strain, which has completely torn the muscle all the way through and usually requires surgery. **JT**

© Getty

When will we find alien life?

Llywelyn Peters

■ It's impossible to say if and when we will find alien life. Given the universe's vast size it seems more likely that we will detect aliens long before we meet them, perhaps from their radio transmissions or from analysing the chemicals in the atmosphere of distant plants for any hints of life. **JS**

© Getty

What's the deepest point dug by a tunnel-boring vehicle?

Severine Blois

■ The Gotthard Base Tunnel, which runs underneath the Swiss Alps, opened in 2016. It was carved by a tunnel-boring machine that dug down to 2.3km under the mountain surface. **JH**

© Getty

Is history always written by the victors?

Hannah Winstone

■ The famous phrase suggests that when two sides clash, the winner writes the history books and portrays themselves in a favourable light. It's certainly not always the case, however. Take the great ancient historian Thucydides – an Athenian – who documented nearly 30 years of war between Athens and Sparta (431–404 BCE), but Sparta won. Or the American Civil War (1861–1865), where there are accounts written by historians from the Confederacy, the losing side. **JT**

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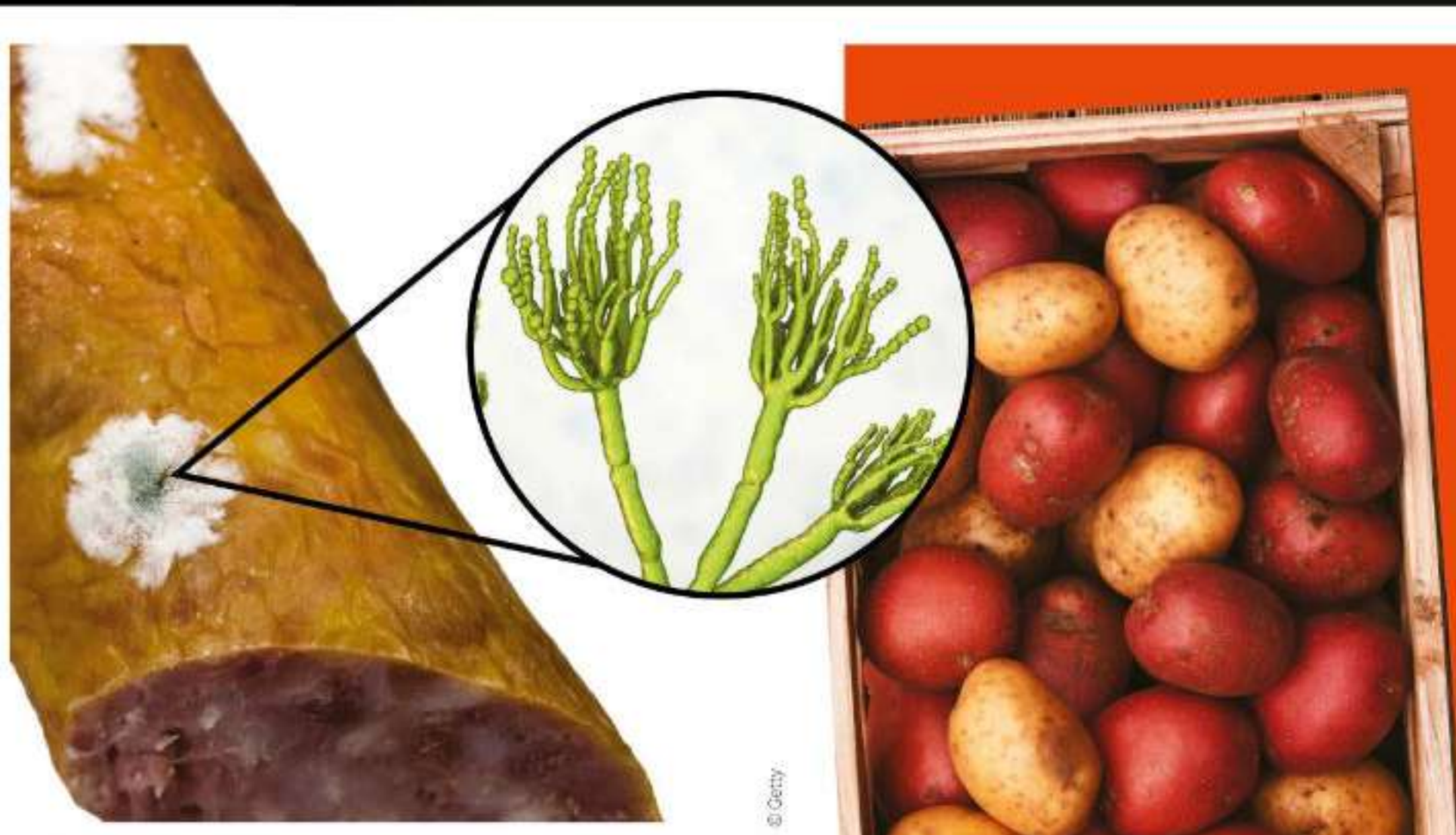
What is the smallest particle, and why isn't it made of something smaller?

Pauli Crawford

John Dalton discovered the atomic theory of structure in the early 1800s. For about a century after this incredible finding, scientists believed atoms to be the most basic building blocks in the universe. However, we now know that every bit of physical matter is made of fundamental particles that compose atoms and everything else. The smallest of these are quarks and leptons, which are too small to accurately measure. But we're not sure if they are also formed of even smaller parts. **JH**

© Alamy

Current instruments cannot detect anything smaller than quarks and leptons



© Getty

Why is rotting meat worse to eat than rotting vegetables?

Chris Fleming

Food spoilage is caused by microorganisms, with fungi and bacteria the most common culprits. Although disgusting, rot-inducing microbes often aren't particularly harmful in either meat or vegetables. However, meat is often thought of as more dangerous. This is because a range of disease-causing food pathogens can reside inside the lymph nodes in meat. **JH**

www.howitworksdaily.com

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Potatoes contain a host of important nutrients but still can't support our bodies alone

Is there a single food that you can survive on forever?

Nora Rigby

Our bodies need a variety of nutrients in order to survive and thrive. These include the major food groups of proteins, fats and carbohydrates, as well as vitamins and minerals. Unfortunately, we've yet to find a single food that has the right mixture of all the nutrient types to sustain us for the long term. However, a popular choice if one was forced to eat just one food (for a while) would be potatoes. These tubers are packed with starch – a complex carbohydrate – but also have a fair amount of protein. Sweet potatoes also have extra vitamins and minerals. But you'd need to eat around 30 sweet potatoes a day to get enough calcium and 30 white potatoes to get enough protein, so it wouldn't be sustainable. **JH**

BOOK REVIEWS

The latest releases for curious minds

Comet: Photographs From The Rosetta Space Probe

Take a closer look at some of the most incredible space photography ever captured

■ Author: **Jean-Pierre Bibring & Hanns Zischler** ■ Publisher: **Thames & Hudson**
■ Price: **£50 (approx $60)** ■ Release: **Out now**

The exploration of the comet 67P/Churyumov-Gerasimenko was one of the most significant scientific endeavours of the century so far. As the Philae lander touched down on the surface of the comet, it unexpectedly bounced (twice) and ended up near a dark cavity. And after months of sending data back to Earth via Rosetta, the spacecraft that carried the lander, Philae's journey finally ended – its battery unable to recharge due to the lack of sunlight.

But this was only a tiny part of the mission's journey – a fact that this photography-led book goes to pains to make. As we turn the pages we soon see shots of the Earth, Moon and planets including Mars and Saturn. The path that the spacecraft took was incredible, because it used the gravity of these planets to slingshot across the Solar System to get close to Jupiter, where 67P was passing by.

The book starts with a foreword that explains the story from long before Rosetta even saw a launchpad. It's packed with interesting facts about how the mission happened, and how the final team came together from three separate teams working on different solutions. From here, we go on to read about the launch, and then the photos begin.

And my goodness, those photos are exceptional. The camera onboard Rosetta and Philae may not have matched the smartphone in your pocket for megapixels, but it had some smart tricks up its sleeve. Which is just as well, because we learn that the comet is as black as charcoal, and it reflects only six per cent of the light that hits it.

The result is a series of photos that at times we struggled to comprehend: not because they are poorly taken or badly annotated – quite the opposite. Rather, it's because 67P has 1/100,000th of Earth's gravity, and has surface temperatures of -133 degrees Celsius. While the photos and captions paint an incredible picture, there's something so alien about the comet and its surface that it's almost impossible to imagine, even when the photos are in front of you.

This is an expensive book, and one that is probably intended more as a conversation starter than a reference, but it doesn't matter. It's still an exceptional celebration of one of mankind's greatest achievements.

★★★★☆

"And my goodness, those photos are exceptional"

Super Space Encyclopedia

The furthest frontier

■ Author: **Clive Gifford**
■ Publisher: **DK**
■ Price: **£16.99 / $24.99**
■ Release: **Out now**

It hasn't been a bad week for space books – indeed, here's another one for your collection. It's not as unique as *Planetarium*, but DK's tried-and-tested layout is implemented here once again, and they would be fools to change a winning formula, as this book proves.

Taking us through the Solar System one planet at a time, followed by its moons, additional stars and exoplanets, before moving on to the history of space exploration itself, this is nothing if not comprehensive. Insightful annotations accompany the awe-inspiring photography that has become a key hallmark of DK's publications. That pages are devoted to Russian and Chinese ventures rather than solely American ones help to give this book a more rounded feel, and they are a welcome inclusion.

Also present are some surprise inclusions teasing the future of space exploration. Ever heard of the robonaut? You'll get to see one in all its glory – the possibilities it teases are truly remarkable.

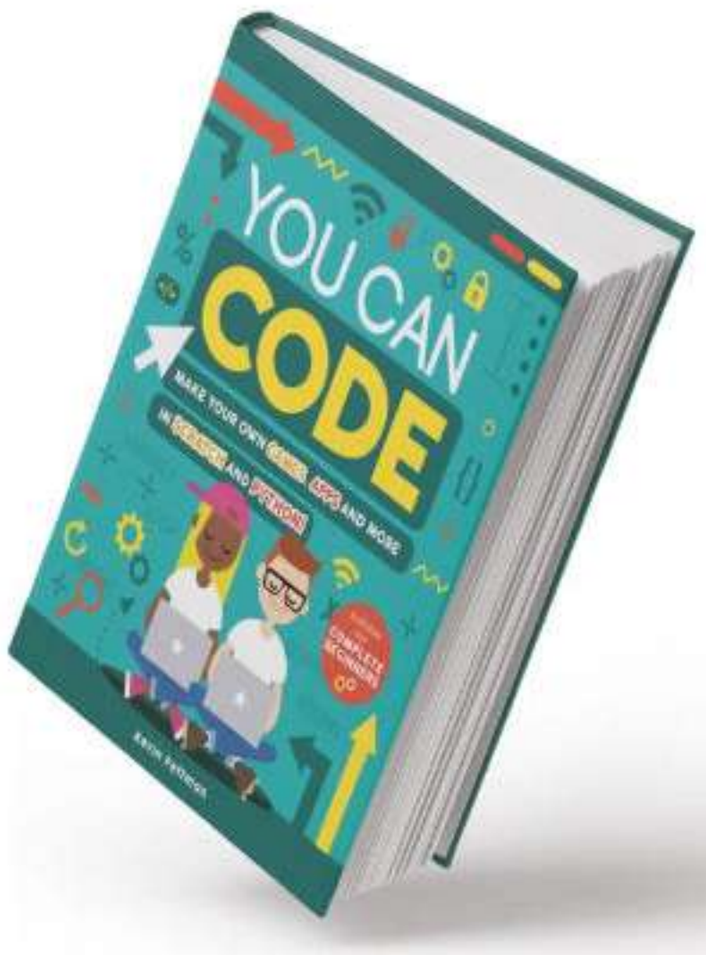
By now you'll know exactly what you're getting from a DK book, and that's no bad thing. DK's titles seem almost like old friends, and it's this familiarity and readability that continue to make them sought after.

★★★★☆

You Can Code

If you say so

- Author: **Kevin Pettman**
- Publisher: **Carlton Kids**
- Price: **£8.99 / $12.95**
- Release: **Out now (UK) / 4 February 2020 (US)**



You'd be forgiven if the concept of programming code was an alien one to you – you've got to love generational gaps. But it's not as complex as it looks. These day, even children are having coding birthday parties. Those of them who have not had this experience, however, might be advised to check this book out.

Using programming languages Scratch and Python as its basis, this takes its readers on a full beginner's guide into the field of coding, talking them through the process of creating games, apps, animations and more. If you know how to switch on a computer, then all of this will be readily accessible to you.

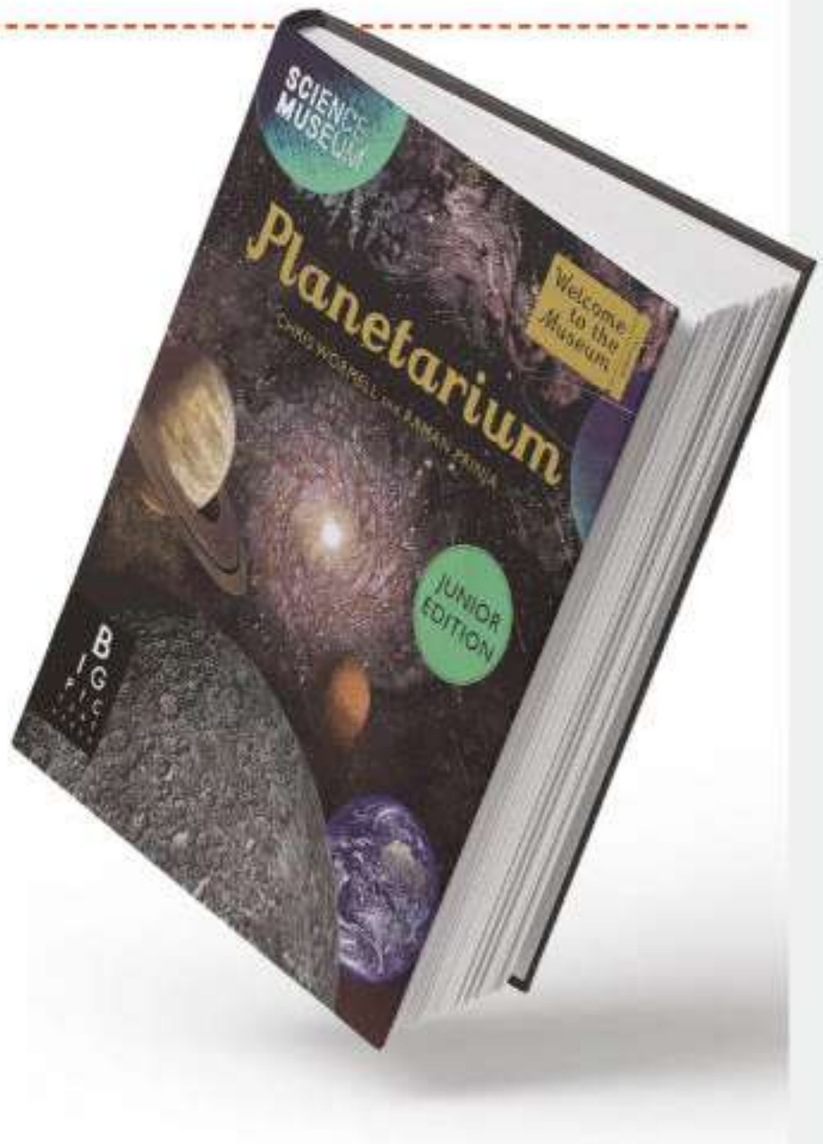
The very youngest readers may need a supervising adult on hand for certain aspects of what's included within, but that's to be expected. What we have here is a rock-solid guide to what is both a rather enjoyable pastime and an increasingly important skill in today's job landscape.

★★★★☆

Planetarium: Welcome To The Museum

Space in your living room

- Author: **Raman Prinja, Chris Wormell**
- Publisher: **Big Picture Press**
- Price: **£10.99 (approx $15)**
- Release: **Out now**



Taking the form of your very own miniature open-all-hours museum, if the aim was to replicate the sense of wonder that we experience when we set foot in real-life planetariums, then we can report that it's mission accomplished.

This is helped in no small part by the illustrations accompanying this. Technically accurate drawings done in the style of a 19th-century artist illustration, they would look at home in a boutique magazine, and they act as an incentive to turn the pages all by themselves.

But that's not to decry everything that accompanies them. Inevitably, being a junior edition, this doesn't go into quite as much detail as it could. But that's by no means a bad thing. Whether describing the Solar System, the night sky, stars or galaxies, every page contains a perfectly digestible introduction to some sort of phenomena that exists out there.

In fact, we'd go so far as to say that this is the perfect accompaniment for those looking to learn about space and beyond for the first time. Attractive presentation coupled with pitch-perfect prose make this an ideal gift for the budding space enthusiast – and quite possibly for existing ones too.

★★★★★

DIY Survival Manual: Natural Disasters

Discover the art of earthquake evasion

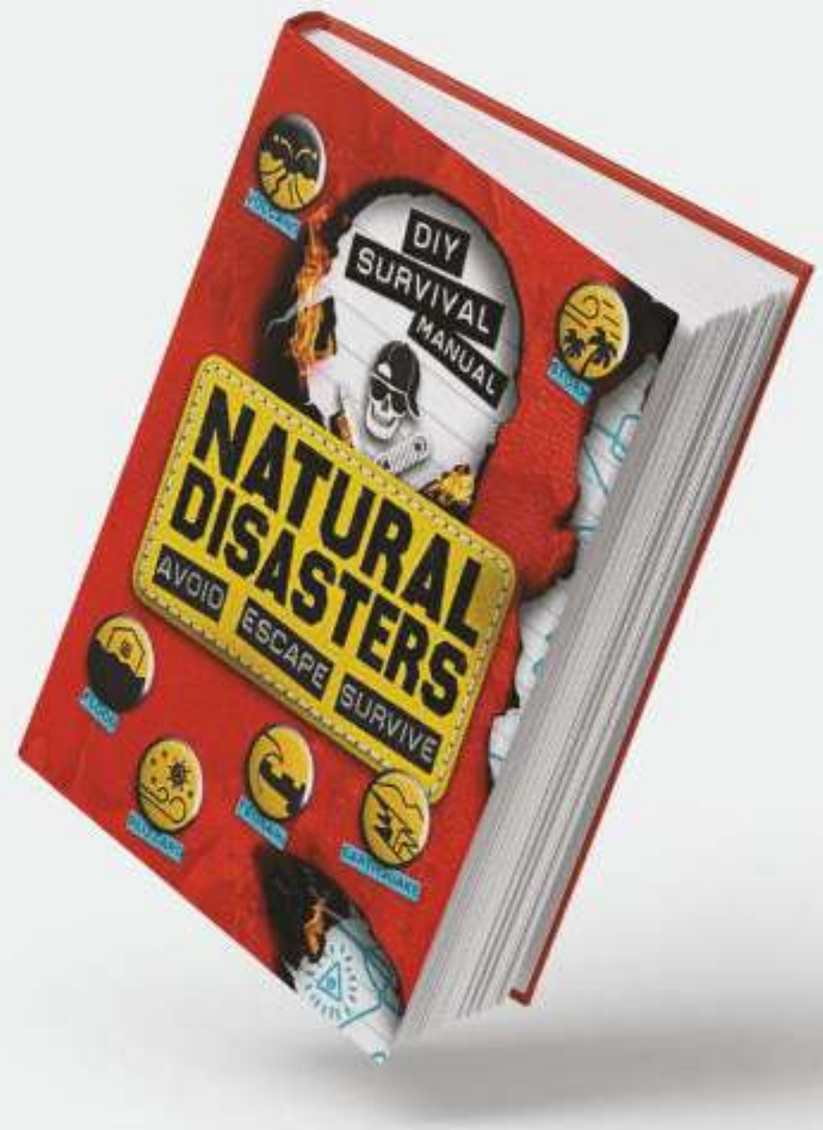
- Author: **Ben Hubbard**
- Publisher: **Carlton Kids**
- Price: **£8.99 (approx $10)**
- Release: **Out now**

Here in the UK, we're in the fortunate position of being relatively safe from the threat posed by natural disasters. We may get the occasional nasty storm or flood, but generally these are small fry compared to what some other countries have to go through.

Although presented in a humorous style, the point being made in this book is a serious one: it aims to arm you with the right know-how when faced by one of these destructive phenomena. Some of this is obvious, like stressing the importance of being prepared and listening to weather warnings, but the rest of it is perhaps not so obvious – we're not going to spoil it and tell you which parts in particular!

Don't go in expecting an in-depth how-to guide – this isn't really equipped with that kind of detail. But it's an interesting diversion for survivalist enthusiasts, at the very least.

★★★☆☆



STRATEGY GUIDE

Carcassonne

Expand and colonise a medieval French kingdom in this competitive land-grab

■ Publisher: **Z-Man Games** ■ Price: **£32.99 / $34.99** ■ Number of players: **2-5** ■ Recommended age: **7+** ■ Typical game time: **35 minutes**

This classic board game involves linking up a jigsaw puzzle of tiles and scoring points according to their placement. Each tile is illustrated with a feature of the Carcassonne landscape – a field, a segment of city, a road or a monastery.

Players take turns to place these tiles, which have to connect so that they make a logical extension of the features on the tiles they face. For example, a road must continue a connecting road, or a segment of city must expand a city it connects to.

Once the player has placed a tile, they have an option of placing one of seven 'meeples' – small wooden followers that allow them to claim a feature, preventing any other player from placing their meeples on the same feature. So a meeple can be placed on a road as long as none of the connecting road tiles have another player's meeple. But two separate features with meeples can be joined by a tile, and in these instances may have more than one meeple on it.

Players score points when they place a tile that completes cites or roads that they have claimed, at which point they can return their meeple to their pool.

The game ends when all the tiles have been used up. The players with the most meeples on each field or incomplete feature are then awarded extra points. Then the player with the most points wins the game.

Gallic gameplay

Several key tactics can be a sure path to claiming victory over your opponents

Meeple
These can be used to score points, but also to stop other players from scoring, so don't rush into placing them everywhere.

Prestigious emblems
These pennants are worth extra points to the player who claims the city they're found in.

Hijack tactics
Wait until a player has put some work into building a big feature, then join your own small feature to it, in an effort to steal their points.

Joining up
A good way to quickly score some points is to start and finish a road by book-ending it with two cities.

Monastery
This building scores one point, plus a single point for every tile it's connected to, for a maximum score of 9.

Feudal fields
A big field can be worth a lot of points, but any meeple placed there stays for the entire game.

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BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

Wordsearch

S	P	E	T	T	A	B	L	Q	O	C	C	X	L	X
F	P	E	R	M	A	F	R	O	S	T	S	X	P	G
U	Z	G	D	D	K	Z	T	X	R	X	D	L	O	C
F	W	M	A	X	V	V	C	K	S	E	G	G	L	X
D	V	B	T	U	Y	H	E	H	Z	U	S	S	Y	F
N	I	C	A	R	E	V	S	Z	L	O	L	X	G	K
G	E	T	O	R	I	X	N	I	S	R	M	A	R	S
C	E	I	N	S	T	E	I	N	Y	L	L	A	A	E
O	O	L	B	U	X	T	I	A	D	L	S	O	P	X
A	E	C	T	X	A	H	T	K	N	O	I	X	H	T
S	A	R	L	O	V	E	L	L	I	S	O	P	R	E
R	K	J	E	V	E	L	X	X	C	Y	T	L	X	T
N	O	I	S	S	I	M	S	N	A	R	T	X	B	X
X	X	X	D	F	V	Q	B	E	Y	E	Q	D	X	J
I	E	N	T	E	R	P	R	I	S	E	A	F	X	L

FIND THE FOLLOWING WORDS...

DATA
TRANSMISSION
POLYGRAPH
EINSTEIN
EYE
BLOOD
COLD
ENTERPRISE
PERMAFROST
MARS
INSECT
LOVELL

Quickfire questions

Q1 How many times faster is 5G than 4G?

- 2
- 10
- 100
- 200

Q2 Who formulated the original principle of relativity?

- Newton
- Galileo
- Einstein
- Copernicus

Q3 In which year will NASA's Dragonfly land on Titan?

- 2025
- 2032
- 2034
- 2041

Q4 Which species has the biggest brain?

- Human
- Blue whale
- Sperm whale
- Elephant

Spot the difference

See if you can find all six changes we've made to the image on the right

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

EASY

	7	3					2	8
	4	5	3		2	9	6	1
9	2	1	8	5			3	7
	8	4	2		5	7		
	9					8	5	
	6			8	3		4	
	3	9		6	1	2		5
2	1	8	5	3	9	6		4
7		6		2	8	3	1	

DIFFICULT

1					2		7	
8		9		7		6	5	
4	3					8		2
		4		2	1			
	6					3		
5					7			
	8							
			6			7	4	
7							1	6

What is it?

Hint: The best lotion can't remove the wrinkles from this at 30x magnification.

A .....

Spot the difference

Check your answers

Find the solutions to last issue's puzzle pages

Quickfire questions

Q1 2

Q2 Africa

Q3 318

Q4 1347

INBOX
Speak your mind...

Get in touch
If you have any questions or comments for us, please send them to:

How It Works magazine @HowItWorksmag howitworks@futurenet.com

The Big Bang is the leading theory for the beginning of the universe

© Getty

Letter of the month

Before the Big Bang

Dear **HIW**,

Thank you for your articles on the Big Bang. Has mankind any idea where the Big Bang came from and what was there before the Big Bang? How did it come about? Also could mankind, accidentally perhaps, cause another Big Bang?

Stephen Conn

This is arguably science's most difficult question to answer, because whatever was around before the Big Bang now resides beyond the known 93 billion-light year sphere of the universe that we live in. We can only see as far back as 300,000 years after the time of the Big Bang, but we've calculated that it occurred around 13.8 billion years ago. At the moment of its birth, an expansion of space itself inflated faster than the speed of light, doubling in size 90 times in a tiny fraction of a second. This event is what we now refer to as the Big Bang, and it has been a theory about the origin of the universe since the 1920s.

However, since then a handful of theories from the world's greatest minds have postulated alternative ideas. This includes the concept of a multiverse, in which our universe has merely broken away from another universe. Others have suggested that the Big Bang was the point at which our universe appeared through the other side of a black hole. But the most commonly accepted theory, and perhaps the bleakest, is that there is nothing beyond our universe and there was nothing before its existence.

Today's physicists are still trying to work out what exactly happened all those billions of years ago. One such way is to recreate a version of the Big Bang on a small scale: using particle accelerators such as the Large Hadron Collider, scientists are attempting to replicate the sub-particle collisions that occurred at the beginning of time to better understand the truth behind our universe.

Scientists at NASA are also developing different telescopes, such as the James Webb Space Telescope (JWST), to look back further towards early-forming galaxies. Planned for launch in 2021, JWST could reveal more about time and space, bettering our understanding of the beginning of everything.

© Getty

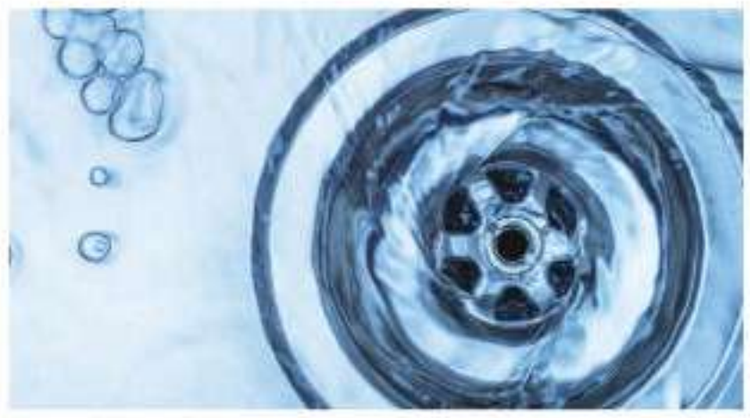
Washing water

Dear **HIW**,

How does water get cleaned after going down the sink?

Paul Chappell

Flowing down the plughole, water is sent on a journey through our underground sewage system to get cleaned. From sink to stream, our waste water is exposed to a multitude of cleaning treatments. Firstly water, along with other general sewage, is passed through a series of screens to physically remove solid waste. Then, moving though biological treatments, microorganisms are added to break down any remaining organic matter. In modern treatment plants, this process is furthered by activated sludge treatment, where air is bubbled through the liquid to encourage bacteria growth. Before going back into natural water systems, the filtered water goes through chemical treatments and biological processes, such as reed beds, to remove contaminants that can be harmful to the environment.



© Getty

Waste water is washed through a series of physical and biological treatments

Cleaning eyeballs

Dear **HIW**,

I have been wondering this for a while, but why do we blink? Do we do it to solely to clean our eyeballs?

Rudolf Lin

On average humans blink around 15-20 times a minute, with each blink lasting only a tenth of a second. Each speedy shut of the eyelid cleans away dust and dirt before it can cause any damage to the eye. However, blinking isn't solely an exercise in good eyeball hygiene but a way to make sure they stay well lubricated. As the skin passes over the eye lens, it carries with it a mixture of oils and mucus to prevent it from drying out.

In a fraction of a second, each blink cleans and hydrates our eyes

© Getty

HIW collection

Dear **HIW**,

We always look forward to the latest edition hitting our doormat! As you can see we are collecting every edition as we often read them again. Our subscription is a gift from our Grandma and think it was wonderful of her. Here is a photo of Ezekiel (aged 12) with lots of his favourite editions. Thank you for keeping us interested and engaged with a wonderful publication.

Ezekiel and Malakai Tejevo

HOW IT WORKS NEEDS YOU!

To celebrate the 10th anniversary of the magazine, we want you to take inspiration from Ezekiel's photograph and snap a shot of yourself with a copy of How It Works. We'll select some of our favourites to be printed in the next issue.

You can email your photographs to *howitworks@futurenet.com* or via Twitter (*@HowItWorksmag*) and Facebook (*@HowItWorksMagazine*). Photos must be received before 11/09/19 in order to be considered.

www.howitworksdaily.com

What's happening on... social media?

If you could time travel back to any historical moment in time, when and where would you go, and why?

@ian40766

"I'd go back to 2 weeks before my exams and do some revision this time!"

@helenharding83

"I would go to when Elizabeth I gave her speech "I have the heart and mind of a king, and a king of England too" after winning the Spanish armada"

@taitanique

"The sinking of the Titanic. I Hove been a researcher for many years so would love to know if various theories are correct."

@angiehoggett

"I'd love to go back to the moon landings, there was so much excitement and pride I'd love to witness it."

@pippyhunt

"I'd go back to be at Woodstock to see Jimi Hendrix play - so iconic and it would have been amazing to have been there!"

NEXT ISSUE...

Issue 130 on sale **3 OCTOBER 2019**

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Future PLC Richmond House, 33 Richmond Hill, Bournemouth, Dorset, BH2 6EZ

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Editor **Ben Biggs**
Senior Art Editor **Duncan Crook**
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Production Editor **James Price**
Staff Writer **Scott Dutfield**
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Contributors
The Art Agency, Stephen Ashby, Lee Cavendish, Curtis Fermor-Dunman, Nicholas Forder, Amy Grisdale, James Horton, Tom Lean, Adrian Mann, Dr Andrew May, John MacNeill, Laura Mears, Jonathan O'Callaghan, Jack Parsons, Joanna Stass, Jodie Tyley, Jon Wells, Victoria Williams, Steve Wright

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Advertising
Media packs are available on request
Commercial Director **Clare Dove**
clare.dove@futurenet.com
Group Advertising Director **Mark Wright**
mark.wright@futurenet.com
Advertising Manager **Toni Cole**
toni.cole@futurenet.com
01225 687368
Media Sales Executive **Jagdeep Maan**
jagdeep.maan@futurenet.com
01225 687353

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Amazing trivia to blow your mind

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IS AROUND 30 MILLION TIMES GREATER THAN AN ANALOGUE TELEPHONE CALL

-18.1° CELSIUS

THE MINIMUM TEMPERATURE THAT ALASKAN WOOD FROGS ARE KNOWN TO SURVIVE, PARTLY FROZEN

1939

THE YEAR THE FBI BOUGHT LEONARDE KEELER'S LIE DETECTOR FOR USE IN INVESTIGATIONS

6

OUT OF THE UK ANTI-DOPING AGENCY'S TEN RULE VIOLATIONS APPLY TO AN ATHLETE'S SUPPORT PERSONNEL AS WELL AS THE ATHLETE

PREHISTORIC SPIDER MEGARACHNE HAD A BODY 60CM LONG AND LIVED 300 MILLION YEARS AGO

ANTARCTIC SCIENTISTS USE A RFID REMOTE-CONTROLLED PENGUIN TO MONITOR PENGUIN HUDDLES

25KPH

THE MAXIMUM CAPABLE SPEED OF AN E-BIKE BEFORE IT NEEDS TO BE LICENSED (UK)

1.5 KM

SIBERIAN PERMAFROST IS INCREDIBLY THICK AT ITS DEEPEST POINTS IN THE NORTH

36

THE AGE AT WHICH ALBERT EINSTEIN PRESENTED HIS THEORY OF GENERAL RELATIVITY TO THE WORLD

A TACHYON

IS A HYPOTHETICAL PARTICLE THAT MOVES FASTER THAN THE SPEED OF LIGHT – BACKWARDS THROUGH TIME

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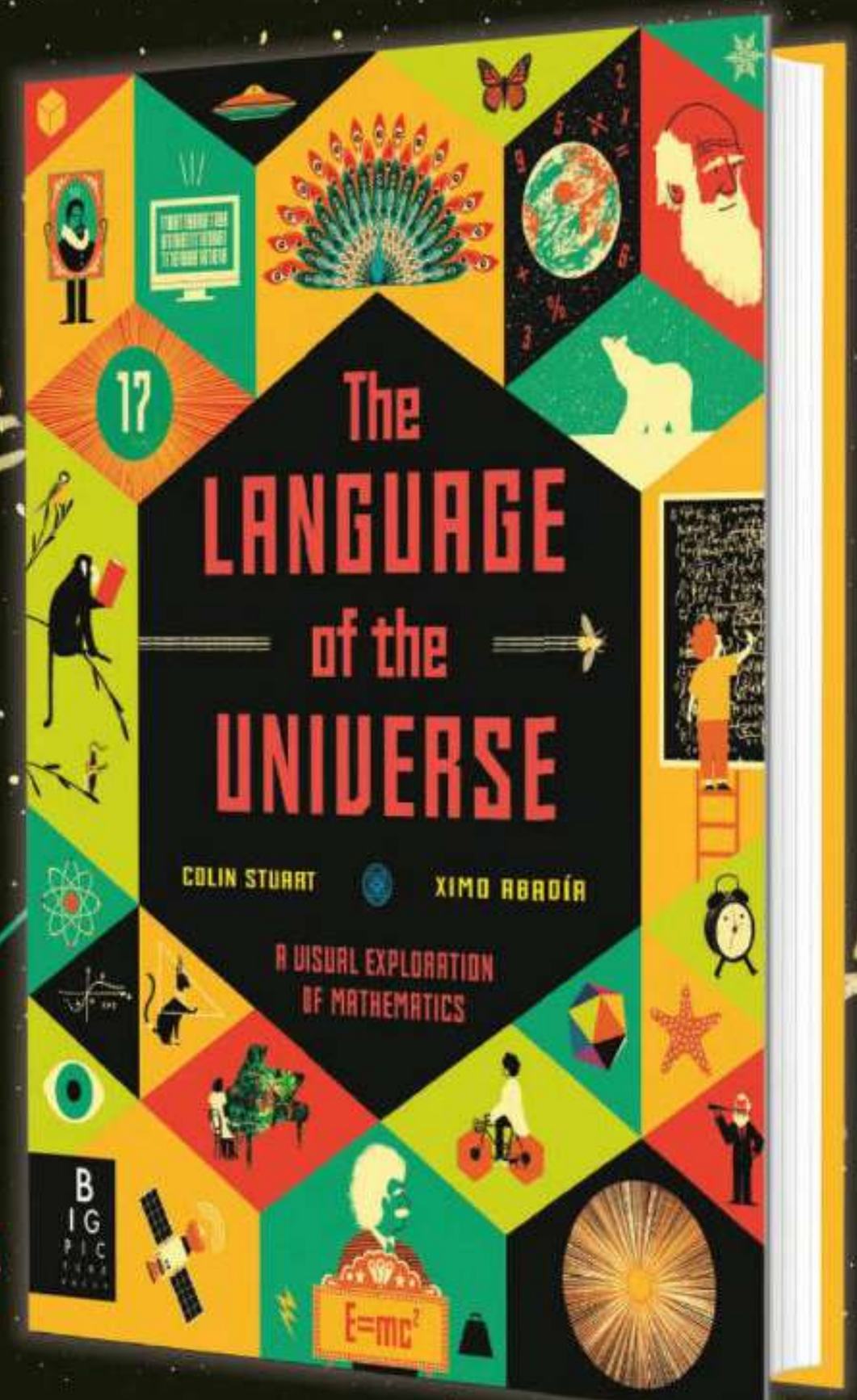

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